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RESEARCH MEMORANDUM

ESTIMATED DECELERATION OF AIRPLANE NOSE SECTION JETTISONED AT VARIOUS ALTITUDES AND AIRSPEEDS

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NATIONAL ADVISORY COMMITTEE
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ESTIMATED DECELERATION OF AIRPLANE NOSE SECTION JETTISONED AT VARIOUS ALTITUDES AND AIRSPEEDS

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SUMMARY

Calculations have been made to determine the deceleration at any time after jettisoning of an airplane nose-section design typical of those which have been proposed as escape devices for high-speed airplanes. The decelerations were determined by two methods, one utilizing successive approximations requiring graphical integration and the other giving reasonably close approximations by direct computation. Decelerations were obtained for the nose section for Mach numbers ranging up to 3.0 and altitudes ranging up to 120,000 feet, and for assumed nose weights of 750 pounds, 1000 pounds, and 1500 pounds. Drag coefficients of the nose at both 0° angle of attack (with stabilizing fins) and 90° angle of attack (without fins) at the various Mach numbers were estimated with the aid of available experimental drag data for spheres and circular cylinders and for bodies of revolution generally similar in configuration to the nose section.

For the 1000-pound nose, estimations based on comparison of the calculated deceleration with such data as are available concerning man's ability to withstand decelerations indicates that, when the nose is stabilized with fins, the deceleration to which a pilot would be subjected would be tolerable for practically all the conditions investigated. For the unstable nose, which turns to an angle of attack of approximately 90° when jettisoned, it is indicated that the pilot would be subjected to cumulative deceleration-time effects which the available data indicate may be intolerable after the nose is jettisoned at Mach numbers greater than 0.95 at 30,000 feet, 1.6 at 60,000 feet, or 3.0 at 85,000 feet.

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INTRODUCTION

A proposed method of providing for emergency pilot escape from airplanes traveling at speeds higher than those at which an ejection-seat method will be adequate consists of jettisoning the nose section of the airplane containing the pilot.

In previous work done by the National Advisory Committee for Aeronautics (references 1, 2, and 3), the behavior of models of jettisonable nose sections has been experimentally determined at subsonic and supersonic speeds and the results have shown that the nose sections are inherently unstable and turn practically 90° to the wind. The results have also shown that a pilot in the nose may be subjected to large decelerations due to the large drag of the nose at high angles of attack and that such decelerations can be avoided by equipping the nose with stabilizing fins to prevent it from turning away from its tip-first attitude. Investigations of the problem of separation of the nose section from the remainder of the airplane (references 3 and 4) have indicated the probable need for forcible forward ejection of a fin-stabilized nose in order to assure clearance and to force the nose forward of a region where high negative lift, due to the nearness of the remainder of the airplane, may cause large accelerations on the pilot. In addition, a method for calculating the path of a jettisoned nose section with respect to the remainder of the airplane while clean separation is being effected is presented in reference 5; use of the method involves a knowledge of the static aerodynamic characteristics of the nose as affected by the nearness of the remainder of the airplane at the flight condition under consideration.

In the present investigation, a nose-section design typical of some proposed designs is assumed to have been jettisoned clear of the remainder of the airplane and calculations are made of the deceleration of the nose at any time after jettisoning at Mach numbers ranging up to 3.0 and at altitudes ranging up to 120,000 feet. The deceleration of the nose at 0° angle of attack (with stabilizing fins) and at 90° angle of attack (without stabilizing fins) for one given weight are determined by a calculation method utilizing successive approximations requiring relatively lengthy graphical integration. A more direct calculation method, requiring less time but giving relatively more approximate results, is used to determine the decelerations of the nose at 90° angle of attack for several assumed nose weights. In addition, the decelerations calculated by the successive-approximations method are compared with existing data concerning man's ability to withstand accelerations or decelerations (reference 6) and estimates are made of the qualitative effects on the pilot of these decelerations.

SYMBOLS

a deceleration, feet per second

g acceleration due to gravity $\left(32.17 \text{ ft/sec}^2\right)$

D drag, pounds

W_n weight of nose section

ρ density of air, slugs per cubic foot

V airspeed, feet per second

V_o initial airspeed, feet per second

M Mach number

M_o initial Mach number

C_D drag coefficient $\left(\frac{2D}{\rho V^2 S_n}\right)$

S_{n_o} frontal area of nose section at 0° angle of attack (10 sq ft)

$S_{n_{90}}$ frontal area of nose section at 90° angle of attack (20 sq ft)

l/d ratio of length to maximum diameter (excluding canopies or other protuberances on nose section)

α angle of attack

t time, seconds

$K = \frac{C_D \rho S_n}{2W_n}$

C constant of integration

CALCULATIONS AND METHODS

The more exact, but relatively lengthy, calculation method was used to calculate the deceleration at any time after jettisoning of a jettisoned nose section with an assumed weight of 1000 pounds and at attitudes of 0° angle of attack and 90° angle of attack. An altitude range from sea level to 120,000 feet and initial Mach numbers ranging from 0.85 to 3.0 were used. The initial deceleration at a given condition of Mach number and altitude was determined by the relation

$$\frac{a}{g} = \frac{D}{W} = \frac{C_D \rho V_o^{\,2} S_n}{2W_n}$$

with values for ρ at each altitude obtained from reference 7 and values for V_o obtained from a plot (fig. 1) of the calculated variation of airspeed with altitude for increments of the speed of sound. The variation of the speed of sound with altitude had been obtained from reference 7 and the form of the convenient plot in figure 1 is based on a similar chart for smaller ranges of altitude and airspeed found in reference 8. Approximate curves of C_D against Mach number used for the typical nose section (see fig. 2 for sketch of nose section) at 0° angle of attack and 90° angle of attack are shown in figure 3. These drag-coefficient curves were approximated with the aid of available experimental drag data for spheres and circular cylinders and for bodies of revolution generally similar in configuration to the nose section. A detailed explanation of how the drag-coefficient curves were approximated is contained in appendix A. In determining the subsequent variation of the initial deceleration of the 1000-pound nose with time after jettisoning, a method of successive approximations utilizing graphical integrations was used. The method neglects the effects of altitude loss and of gravity and is generally similar to a method described in reference 5. In brief, the method is as follows: After noting the initial velocity of the nose from figure 1, an assumed curve of the variation of deceleration with time was drawn and integrated graphically for small periods of time in order to obtain the change in velocity during each period and thereby to obtain the velocity at the end of each period. For the various velocities, values of M were obtained from figure 1 and, for these values of M, C_D for the nose was obtained from figure 3. By using these values of V and C_D at a given time, the deceleration of the nose at that time was calculated by

$$\frac{a}{g} = \frac{C_D \rho V^2 S_n}{2W_n}$$

and the value was plotted for comparison with the assumed deceleration-time curve. The entire process was repeated until the calculated values of deceleration at each time were in agreement with the last assumed deceleration-time curve.

To determine values for the deceleration of the nose at any time after jettisoning by a more direct, but relatively more approximate, method, the relation

$$\frac{a}{g} = \frac{K{V_o}^2}{(1 + gKV_o t)^2}$$

was used. This relation was obtained as shown in appendix B and not only neglects the effects of altitude loss and of gravity as in the previously mentioned method of successive approximations, but also is based on the assumption of a constant drag coefficient for the nose. Decelerations were calculated for the nose at 90° angle of attack for assumed nose weights of 750 pounds, 1000 pounds, and 1500 pounds, corresponding, respectively, to values of $W_n/S_{n_{90}}$ of 37.5, 50, and 75. The calculations were made for an altitude range of sea level to 120,000 feet and for initial Mach numbers ranging from 1.0 to 3.0. A constant drag coefficient of 1.0 was assumed, inasmuch as figure 3 indicates such a value to be representative of the general order of C_D for a nose at 90° angle of attack in the Mach number range under consideration.

RESULTS AND DISCUSSION

Calculated initial decelerations of the 1000-pound nose with and without stabilizing fins are presented in figures 4 and 5, respectively, as plots of deceleration against altitude for various initial Mach numbers. As may be seen from the figures, the finned nose when jettisoned for any given condition of initial Mach number and altitude has less deceleration than does the nose without fins. This lower value of deceleration is to be expected because of the lower drag coefficient and smaller exposed frontal area of the nose when at 0° angle of attack. These calculated initial decelerations, in general, showed qualitative agreement with the results of a few experimental tests (reference 2) of models of the same nose section.

As a result of the deceleration of the nose, a pilot seated in the fin-stabilized nose would be subjected to transverse deceleration, which acts fore and aft through the body and is the type he can best tolerate; a pilot in the unstable nose pitched down to an angle of attack of 90°

would be subjected to longitudinal deceleration which acts along the backbone so as to cause blood to move toward the head and is the type to which he has the least tolerance. A number of deceleration-time variations for the 1000-pound nose at 0° and 90° angle of attack were calculated by the method of successive approximations, previously explained, and a few of these are illustrated in figure 6. The results indicate a gradually decreasing deceleration for the nose after jettisoning at any Mach number or altitude. Although no data were available to specify the limits to which a man can tolerate cumulative effects of such gradually decreasing decelerations, experimental data were available (reference 6) which indicated the approximate time intervals for which a man could tolerate a constant or specific value of deceleration; these data are reproduced as figure 7. In order to evaluate the present calculated decreasing decelerations (such as those in fig. 6) in terms of a pilot's ability to withstand these decelerations, an assumption was made that a man can tolerate cumulative effects of any decreasing deceleration as long as the deceleration values always remain below the curve in figure 7. Although nonconservative, this assumption nevertheless appears fairly justifiable for making the present estimation inasmuch as it has been indicated that recent experience by the Air Force points to the possibility that man's tolerance to deceleration may be somewhat greater than that indicated in reference 6. The effects of the decelerations on the pilot are indicated in figure 8 as plots of the variation with altitude of the flight initial Mach number above which deceleration of the nose would cause intolerable deceleration-time effects on the pilot. As can be seen from the figure, the results indicate that the deceleration-time effects to which a pilot in the 1000-pound nose at 0° angle of attack would be subjected would be tolerable for practically all conditions investigated; whereas, for the nose at 90° angle of attack, he would be subjected to cumulative deceleration-time effects which the available data indicate may be intolerable after jettisoning at initial Mach numbers greater than 0.95 at 30,000 feet, 1.6 at 60,000 feet, and 3.0 at 85,000 feet.

The results of calculations of the deceleration of noses at 90° angle of attack by the more direct, but relatively more approximate, method, previously explained, with values of $W_n/S_{n_{90}}$ of 37.5, 50, and 75 are presented on figures 9, 10, and 11 as plots of deceleration against altitude for various initial Mach numbers at various time intervals after jettisoning. Based on comparison of these approximate results with graphically obtained deceleration-time variations such as those of figure 6, it appears that, for initial Mach numbers ranging from 1.0 to 3.0, the decelerations obtained are within ±10 percent of those given by the more exact, but relatively lengthy, successive-approximations method. Brief analysis of the accuracy of decelerations that would be obtained if the direct-calculation method were to be applied to the determination of decelerations of the nose at 0° angle

of attack for initial Mach numbers ranging from 1.0 to 3.0 indicates that percentage errors considerably larger than those for the nose at 90° angle of attack would be obtained. These larger percentage errors would be due to the fact that an increment of drag coefficient between a representative constant value and a value taken from the drag coefficient curves on figure 3 would be a much larger percentage for the nose at 0° angle of attack than for the nose at 90° angle of attack. In general, it may be said that, if the direct-calculation method is used for the nose at either 0° or 90° angle of attack, the accuracy of the resulting decelerations will depend on the magnitude of the Mach number range over which the representative drag coefficient is assumed to be constant. For greater accuracy, of course, a smaller Mach number range should be used with a given assumed drag coefficient. Depending on the accuracy desired and on the Mach number range over which decelerations are to be obtained, it may be desirable to assume a series of constant drag coefficients, each to be used for a given incremental Mach number range and to calculate the decelerations for each of these incremental ranges by using the velocity at the end of the previous incremental range as the initial velocity and letting time be equal to zero at the beginning of the incremental range. Thus, the accuracy of this method would approach that of the method of successive approximations.

CONCLUDING REMARKS

Calculations have been made of the deceleration at any time after jettisoning of a jettisonable nose section design typical of those which have been proposed as escape devices on high-speed airplanes. The decelerations were determined by two methods, one utilizing successive approximations requiring graphical integration, and the other giving reasonably close approximations by direct computation. Decelerations were obtained for the nose section for Mach numbers ranging up to 3.0 and altitudes ranging up to 120,000 feet, and for assumed nose weights of 750 pounds, 1000 pounds, and 1500 pounds. For the 1000-pound nose, estimations based on comparison of the decelerations calculated by successive approximations with such data as are available concerning man's ability to withstand decelerations indicate that, when the nose is stabilized with fins, the deceleration to which a pilot would be subjected would be tolerable for practically all the conditions investigated, whereas a pilot in the unstable nose would be subjected to cumulative deceleration-time effects which the available data indicate

may be intolerable after jettisoning at Mach numbers greater than 0.95 at 30,000 feet, 1.6 at 60,000 feet, and 3.0 at 85,000 feet.

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APPENDIX A

APPROXIMATION OF CURVES OF DRAG COEFFICIENT AGAINST MACH NUMBER FOR THE NOSE AT 0° ANGLE OF ATTACK AND AT 90° ANGLE OF ATTACK

It was found possible to estimate a value of C_D for the nose at 0° angle of attack for one Mach number (1.72). The drag-coefficient curve (C_D against M) was then drawn through this estimated value of C_D in such a manner that in the lower part of the Mach number range ($M < 1.72$) under consideration the variation is generally similar in shape to an experimentally determined drag-coefficient curve for a spinning projectile (reference 9), and in the upper part of the Mach number range ($M > 1.72$) the curve is a mean line between a line parallel to the drag-coefficient curve for the spinning projectile and a line parallel to an experimentally determined drag-coefficient curve for a finned missile model (reference 10). (See fig. 12.) The estimated value of C_D mentioned previously (for M of 1.72) was determined by totaling the fore drag coefficient for the nose as obtained from reference 11 with base and fin drag coefficients taken from measured values in reference 12 for a small model (2.25-in. diam.) of a missile generally similar to the nose in shape and in l/d. The value of fore drag coefficient used was qualitatively checked by calculations based on model pressure-distribution measurements from reference 13. Use of the results for the relatively small scale model for the base drag coefficient and for the fin drag coefficient, as well as the drawing of part of the drag-coefficient curve for the nose with a shape similar to the drag-coefficient curve for a spinning projectile, appears justifiable inasmuch as reference 14 indicates that the effects of scale or of projectile spinning rotation on drag characteristics at supersonic speeds for bodies of revolution similar to the jettisonable nose are fairly small.

In approximating a drag-coefficient curve for the nose section at 90° angle of attack, attempts were first made to obtain drag-coefficient curves for a sphere and for a circular cylinder having an l/d of 2.8 (same l/d as for the nose section), based on an assumption that the drag-coefficient curve for the nose would lie somewhere between these two curves. Experimentally determined drag-coefficient curves for spheres were obtained from results in references 15 and 16 and from unpublished results of an NACA investigation and show good agreement (fig. 13); no drag-coefficient data were available for circular cylinders with finite values of l/d in the Mach number range under consideration (0.85 to 3.0), but data were available for infinitely long cylinders (reference 17).

Although the experimental drag-coefficient data for both spheres and infinitely long circular cylinders are for models 3 inches or less in diameter, the data are considered applicable in the present nose-jettison problem inasmuch as references 16 and 17 indicate that scale effects are relatively unimportant as regards C_D values for such bodies in the Mach number range under consideration. An attempt was made to obtain a drag-coefficient curve for a circular cylinder with an l/d of 2.8 by using a suggested rough-estimation method from reference 17 based on the data for infinitely long cylinders; however, the results indicated values of C_D which appear unreasonably low. (See fig. 13.) One of the factors which may have caused these estimated values of C_D to be so low is that the drag-coefficient data used to draw the curve for the infinitely long cylinders in reference 17 in the Mach number range of 0.85 to 2.2 may have been erroneously low inasmuch as they were taken from uncorrected wind-tunnel data (fig. 13) from references 18 and 19.

In view of these considerations, the drag-coefficient curve for the nose at 90° angle of attack was drawn above the experimental drag-coefficient curves for spheres and below the experimental drag-coefficient curve for infinitely long circular cylinders in such a manner that it is generally similar in shape to the drag-coefficient curve for spheres, but has its maximum drag-coefficient value at an arbitrarily chosen Mach number about midway between the Mach numbers at which the spheres and the cylinders reach their respective maximum drag coefficients. As can be seen from figure 13, the curve was drawn so that the drag coefficients were of the order of 1.0 in the Mach number range under consideration (0.85 to 3.0). Also, the curve was drawn so that an extension to lower Mach numbers would result in a curve which would be below an experimentally determined subsonic drag-coefficient curve from reference 20 for a circular cylinder with an effective l/d about three times that of the nose. (As regards the drag characteristics of this circular cylinder, it is of interest to note that measurements at higher Mach numbers would probably indicate an increase in drag coefficient similar to that shown in figure 13 for subsonic drag measurements on infinitely long cylinders from reference 21.) As can be seen from figure 13, the extended drag-coefficient curve would approach a C_D value measured experimentally at a low Mach number for the nose (reference 22).

APPENDIX B

DETERMINATION OF RELATION FOR CALCULATING APPROXIMATE DECELERATION OF A NOSE AT ANY TIME AFTER JETTISONING

As mentioned in the text,

$$\frac{a}{g} = \frac{C_D \rho S_n V^2}{2W_n}$$

Therefore,

$$a = \frac{C_D \rho S_n V^2 g}{2W_n}$$

Assuming a constant altitude and drag coefficient and letting

$$K = \frac{C_D \rho S_n}{2W_n}$$

gives the deceleration

$$a = -\frac{dV}{dt} = gKV^2$$

Rearranging gives

$$-\frac{dV}{V^2} = gKdt$$

and integrating gives

$$\frac{1}{V} = gKt + C$$

To satisfy the above expression when time is zero, C must be $\frac{1}{V_o}$
Therefore

$$\frac{1}{V} = gKt + \frac{1}{V_o}$$

Rearranging gives

$$V = \frac{1}{\frac{1}{V_o} + gKt} = \frac{V_o}{1 + gKV_ot}$$

and, by substitution,

$$a = -\frac{dV}{dt} = gKV^2 = \frac{gKV_o^{\,2}}{(1 + gKV_ot)^2}$$

Rearranging gives

$$\frac{a}{g} = \frac{KV_o^{\,2}}{(1 + gKV_ot)^2}$$

which is the expression for approximating the deceleration of a nose at any time after jettisoning.

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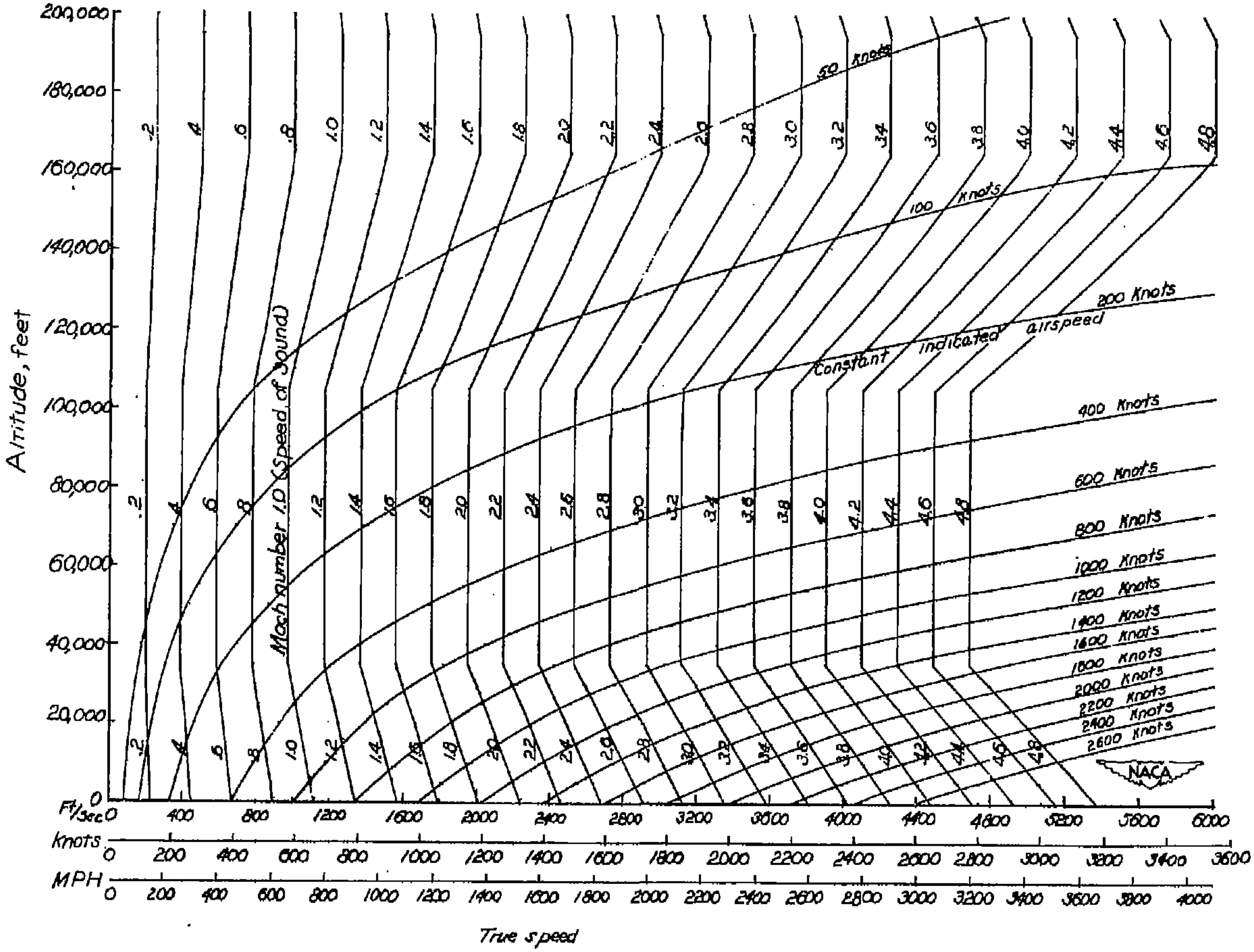

Figure 1.- Variation of airspeed with altitude for increments of the speed of sound.

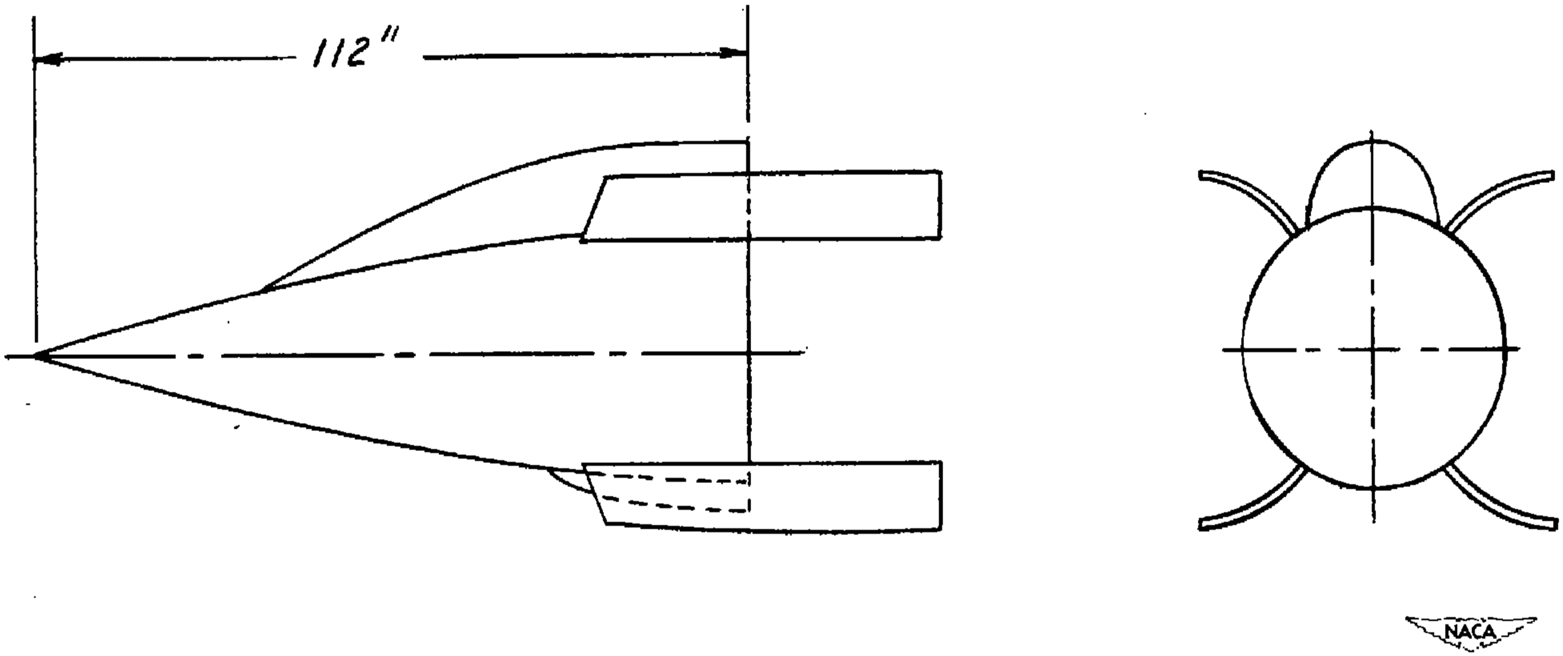

Figure 2.- Sketch of nose section. Curved stabilizing fins (retracted against fuselage during normal flight, references 1 and 2) shown attached.

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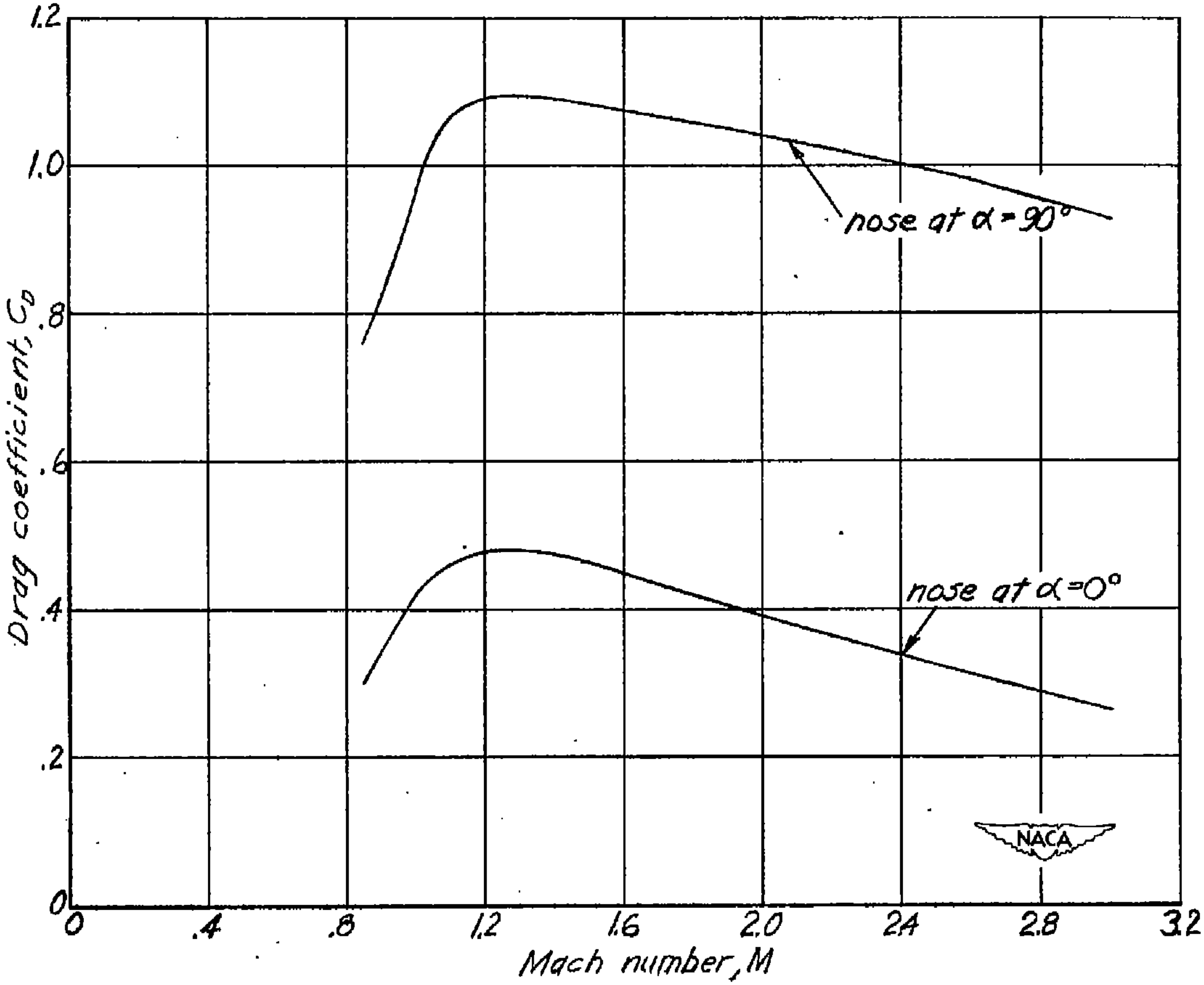

Figure 3.- Variation of drag coefficient with Mach number for nose at 0° and 90° angles of attack.

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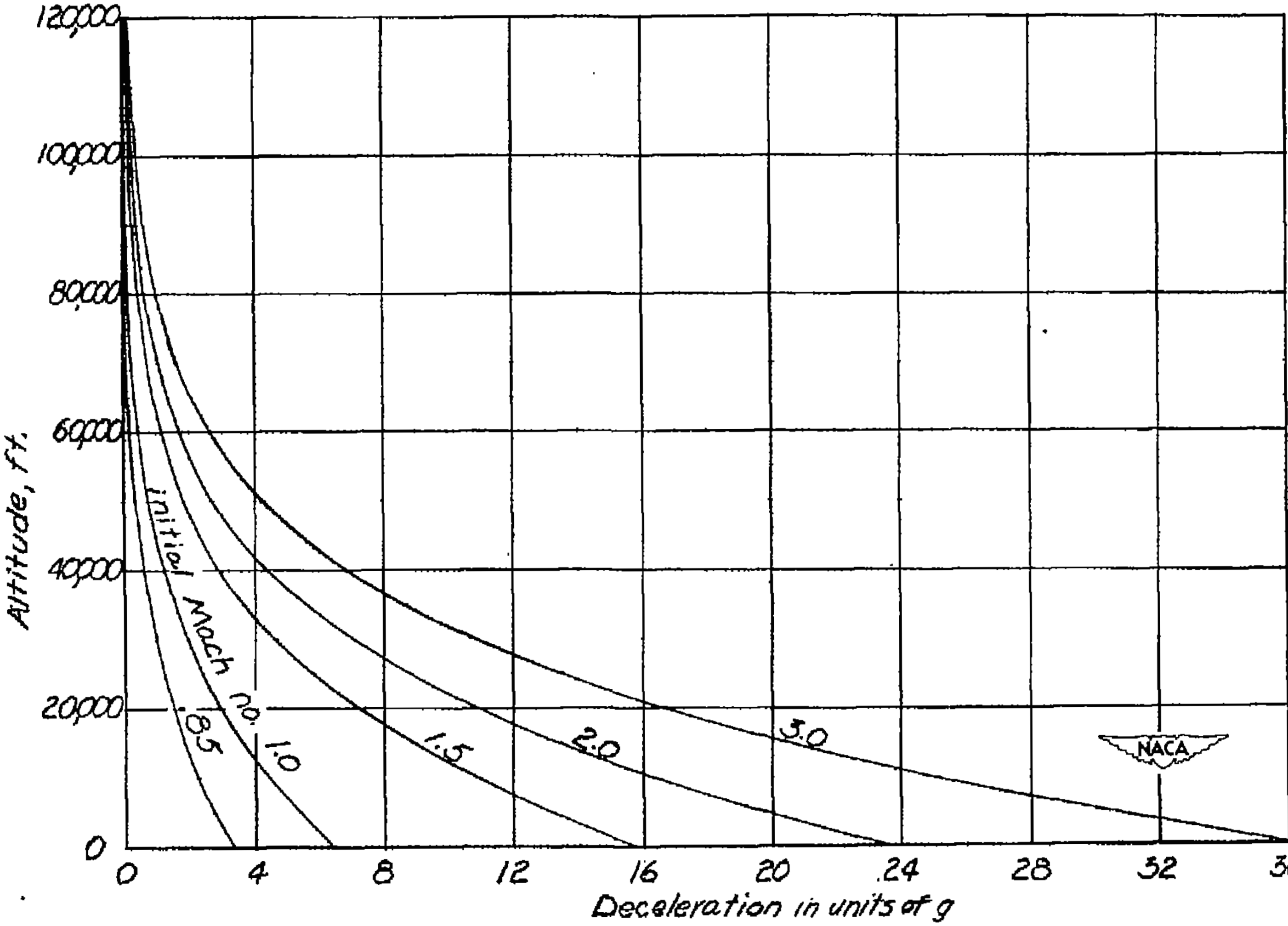

Figure 4.- Calculated initial deceleration of 1000-pound fin-stabilized nose $\left(\frac{W_n}{S_{n_o}} = 100\right.$ at 0° angle of attack$\left.\right)$ for various altitudes and initial Mach numbers using drag coefficients obtained from figure 3.

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[redacted]

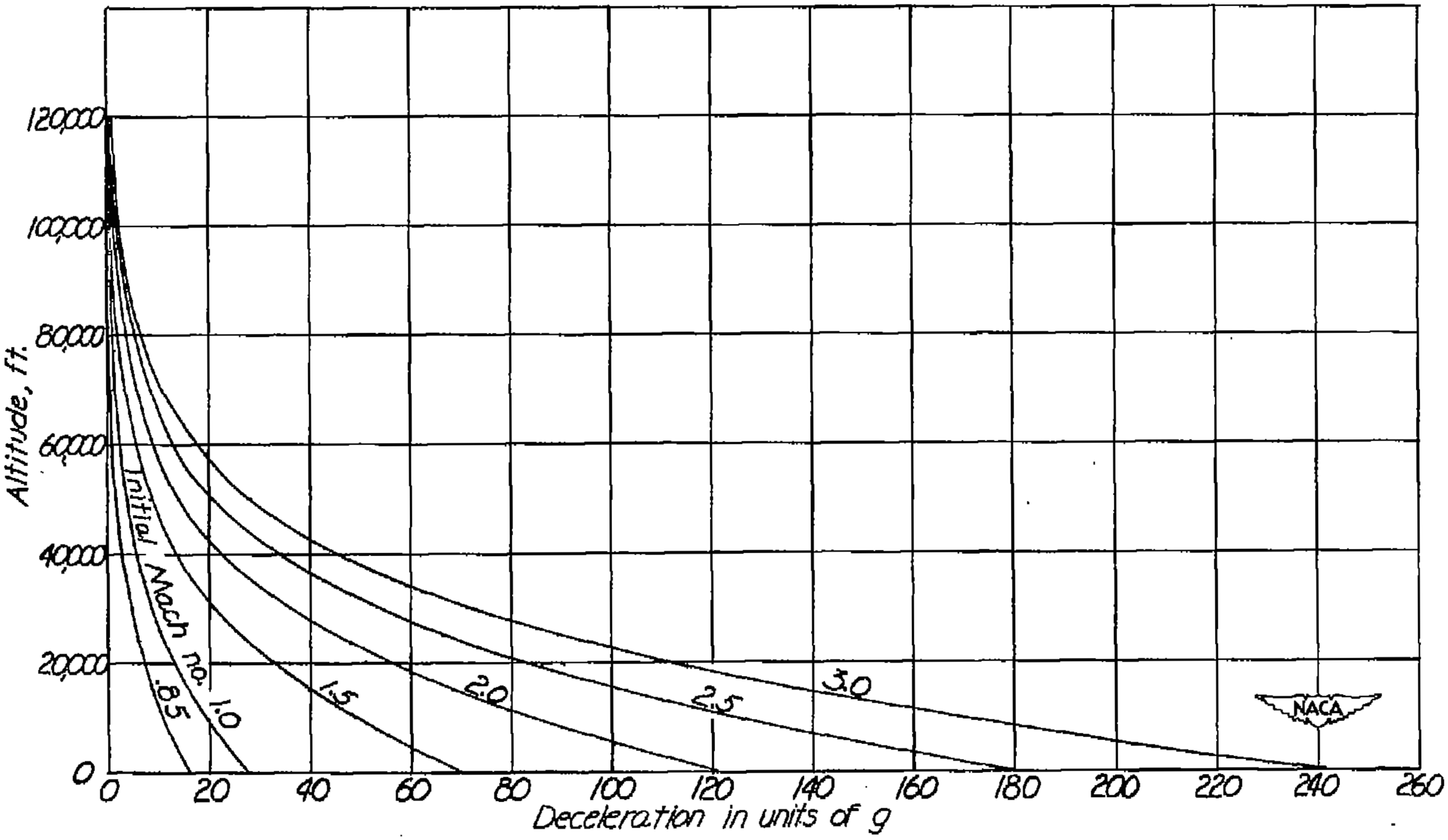


Figure 5.- Calculated initial deceleration of 1000-pound unstable nose $\left(\frac{W_n}{S_{n_{90}}} = 50 \text{ at } 90^{\circ} \text{ angle of attack}\right)$ for various altitudes and initial Mach numbers using drag coefficients obtained from figure 3.

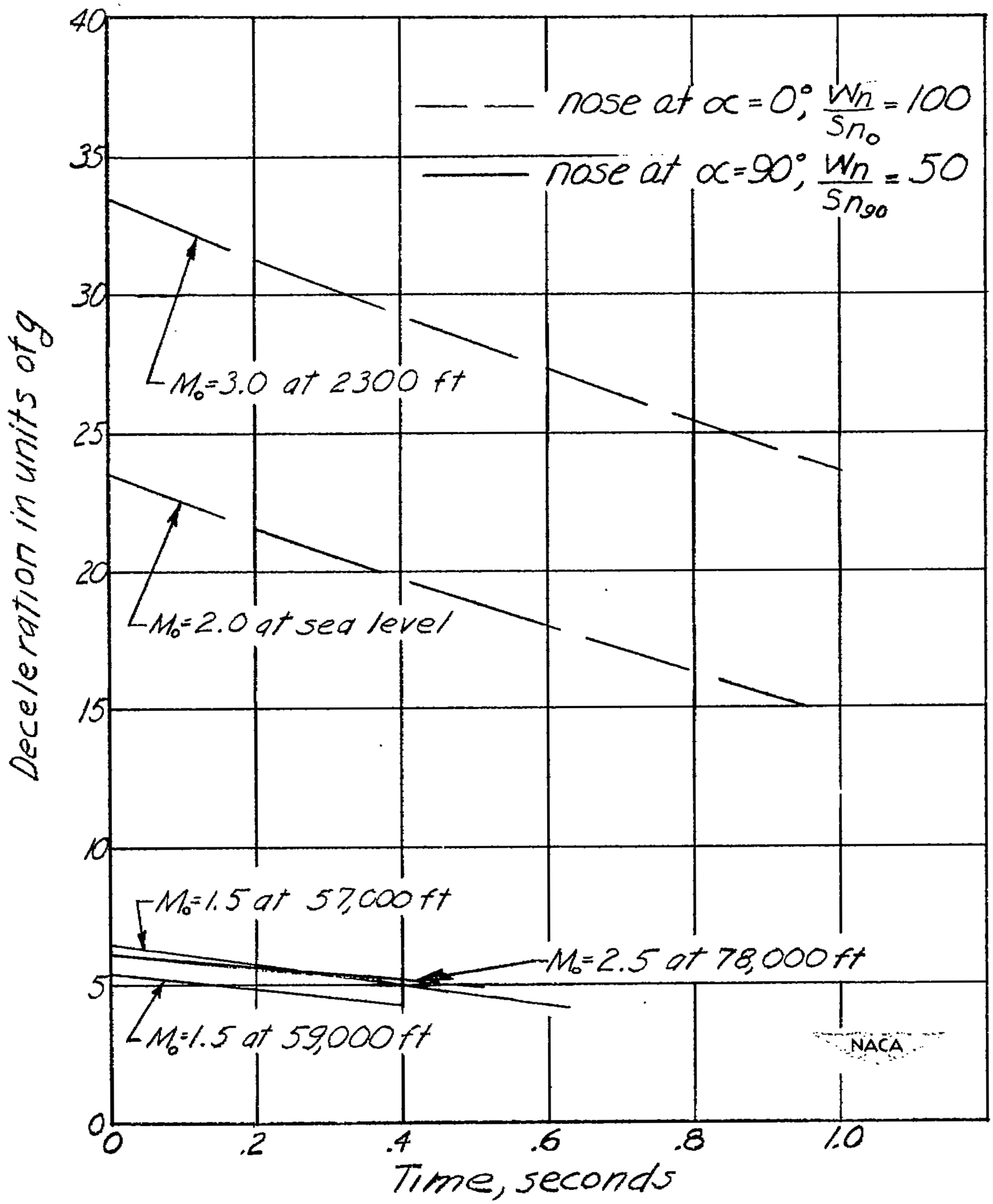


Figure 6.- Calculated variations of the deceleration of 1000-pound nose with time. Successive-approximations method.

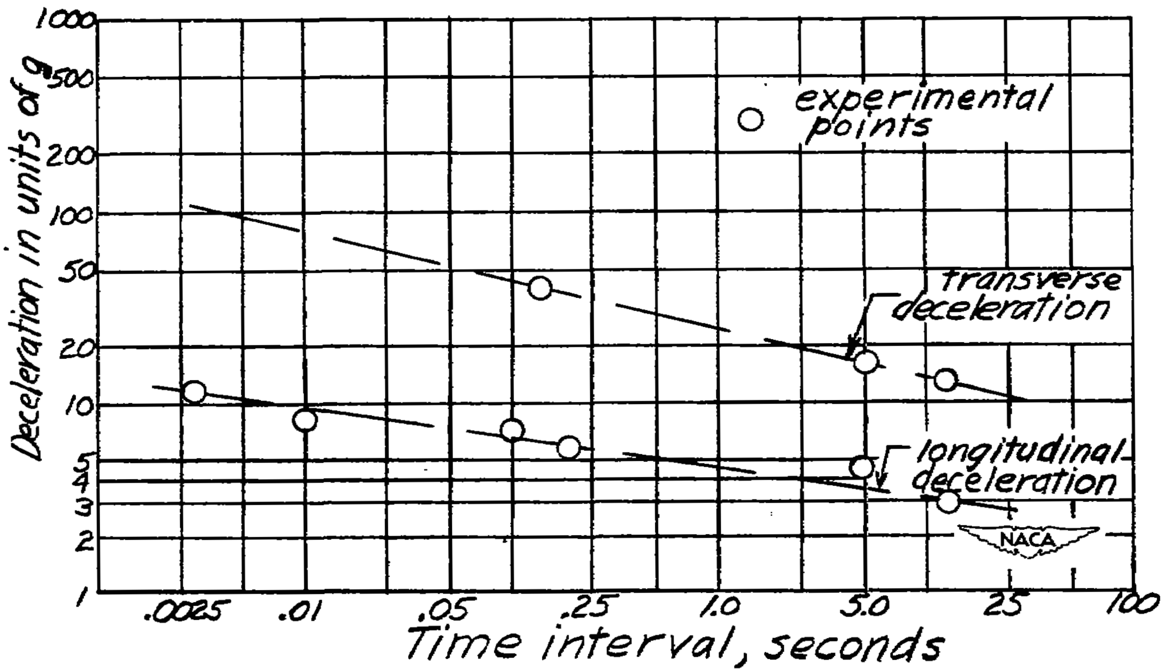


Figure 7.- Amount of nonvarying deceleration that can be withstood by a man for a given time interval, as obtained from reference 6.

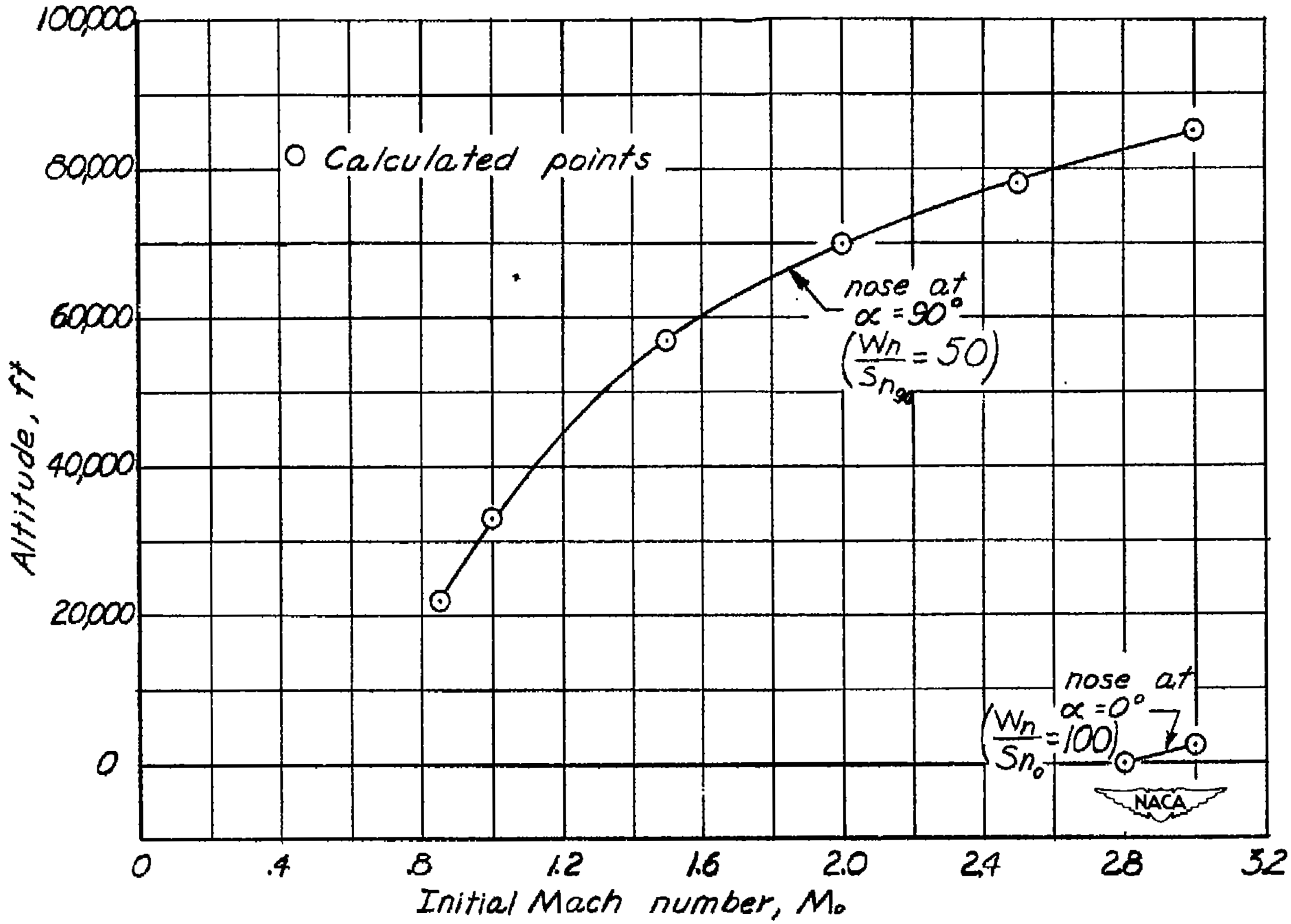
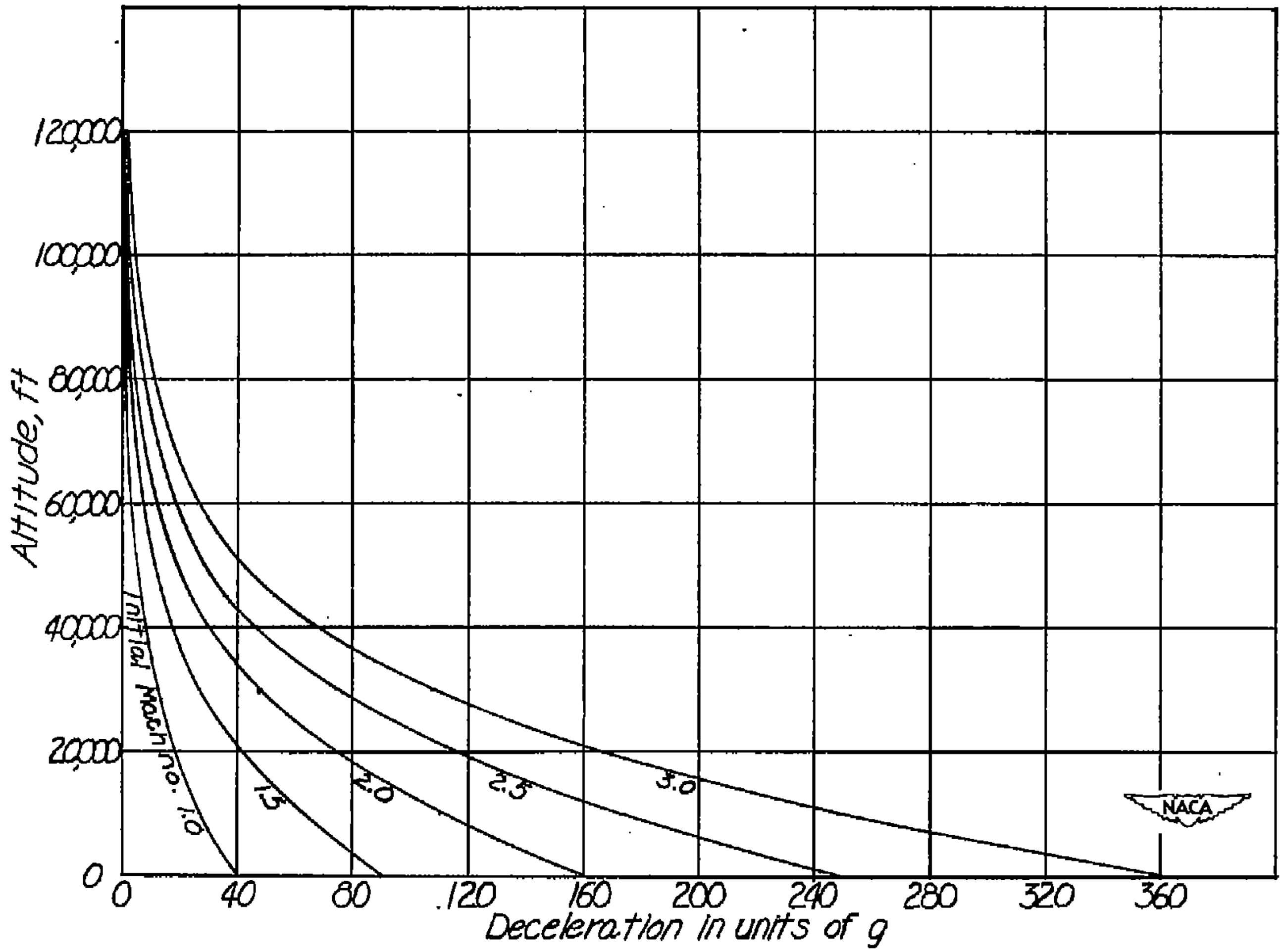


Figure 8.- Estimated variation with altitude of initial Mach number above which deceleration of 1000-pound nose may cause intolerable deceleration-time effects on pilot.



(a) Time = 0 second.

Figure 9.- Calculated decelerations at various time intervals after jettisoning of 750-pound unstable nose $\left(\frac{W_n}{S_{n_{90}}} = 37.5 \text{ at } 90^{\circ} \text{ angle of attack}\right)$ for various altitudes and various initial Mach numbers. Direct-calculation method assuming constant drag coefficient of 1.0.

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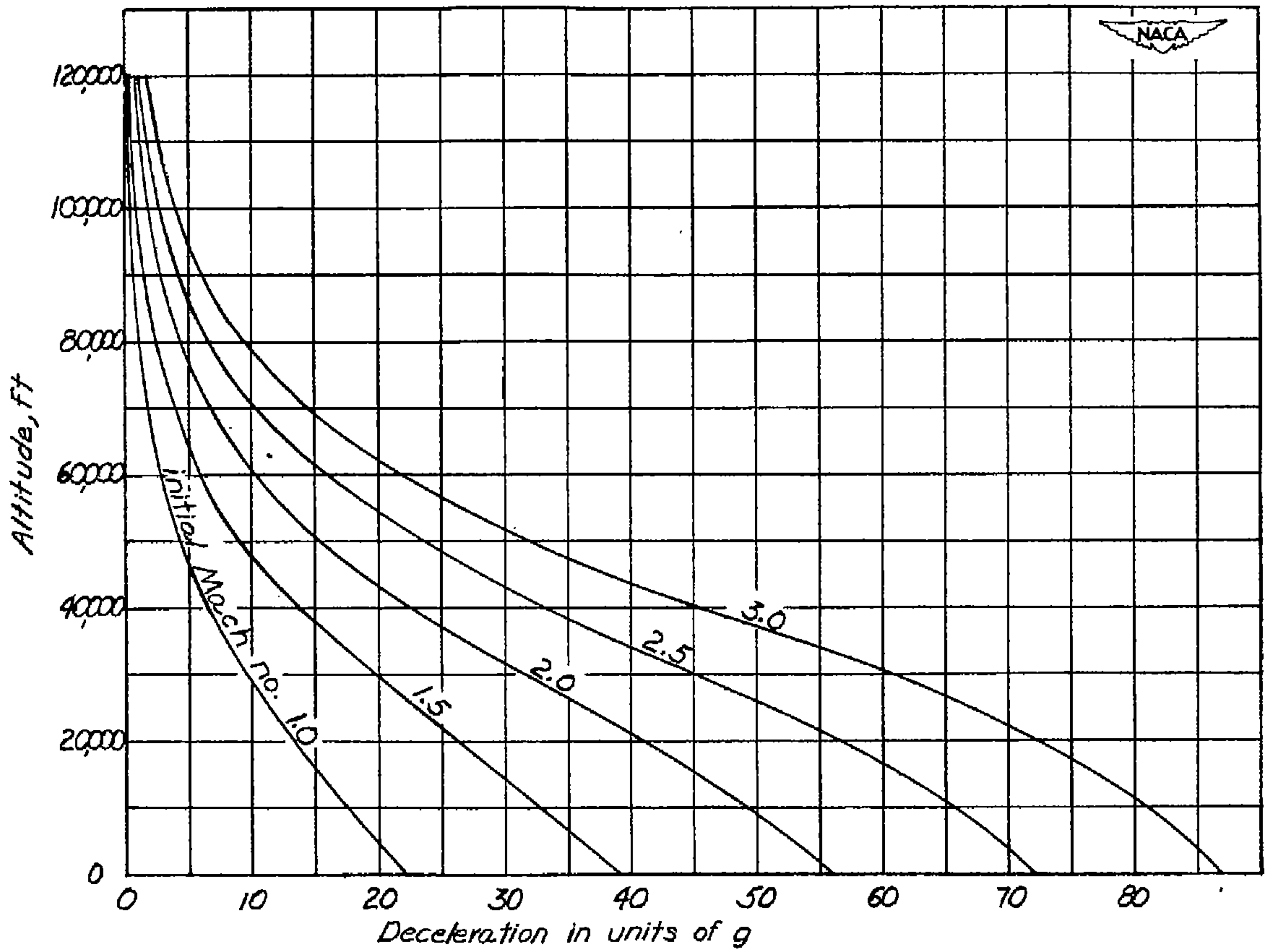

(b) Time = 0.3 second.

Figure 9.- Continued.

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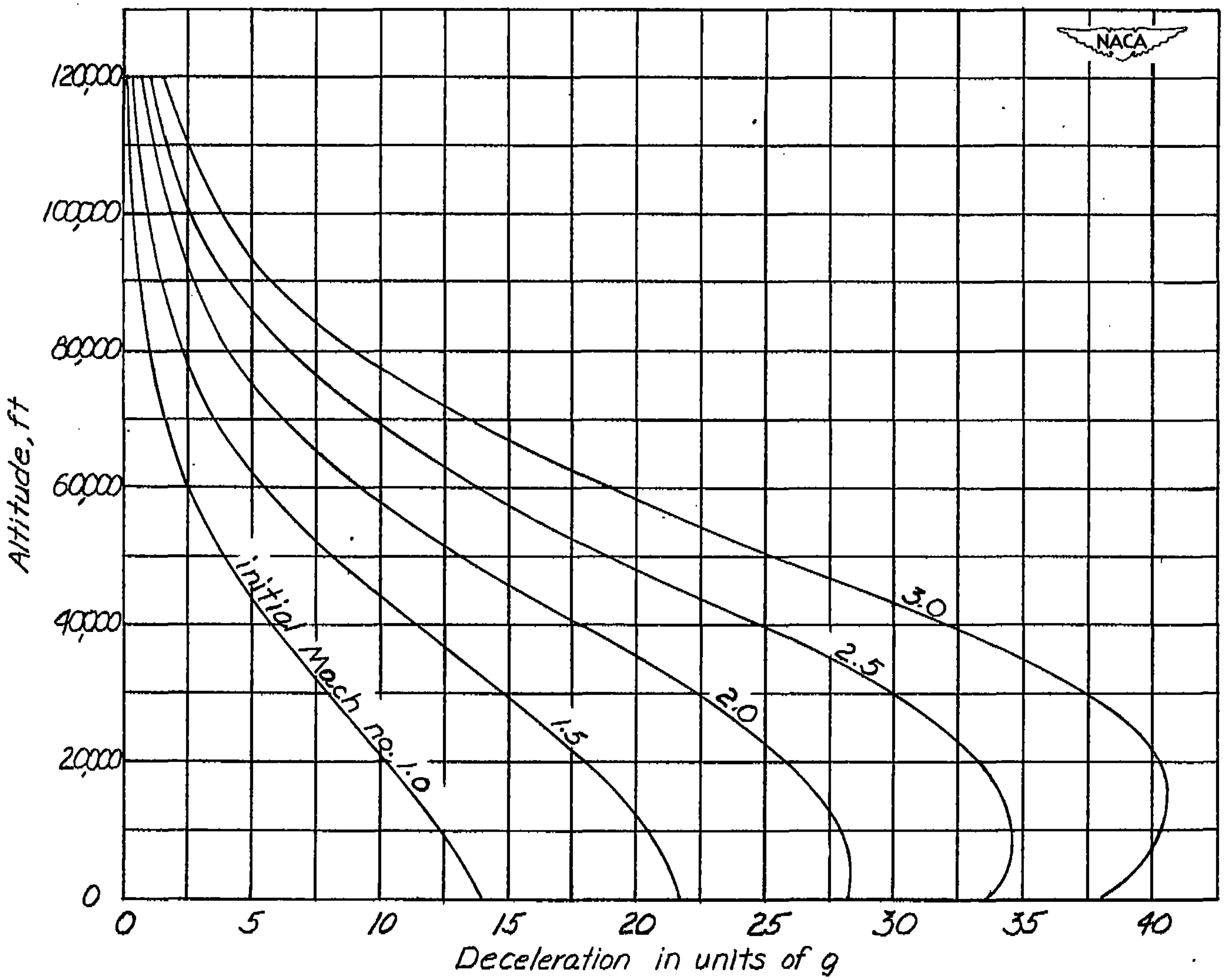
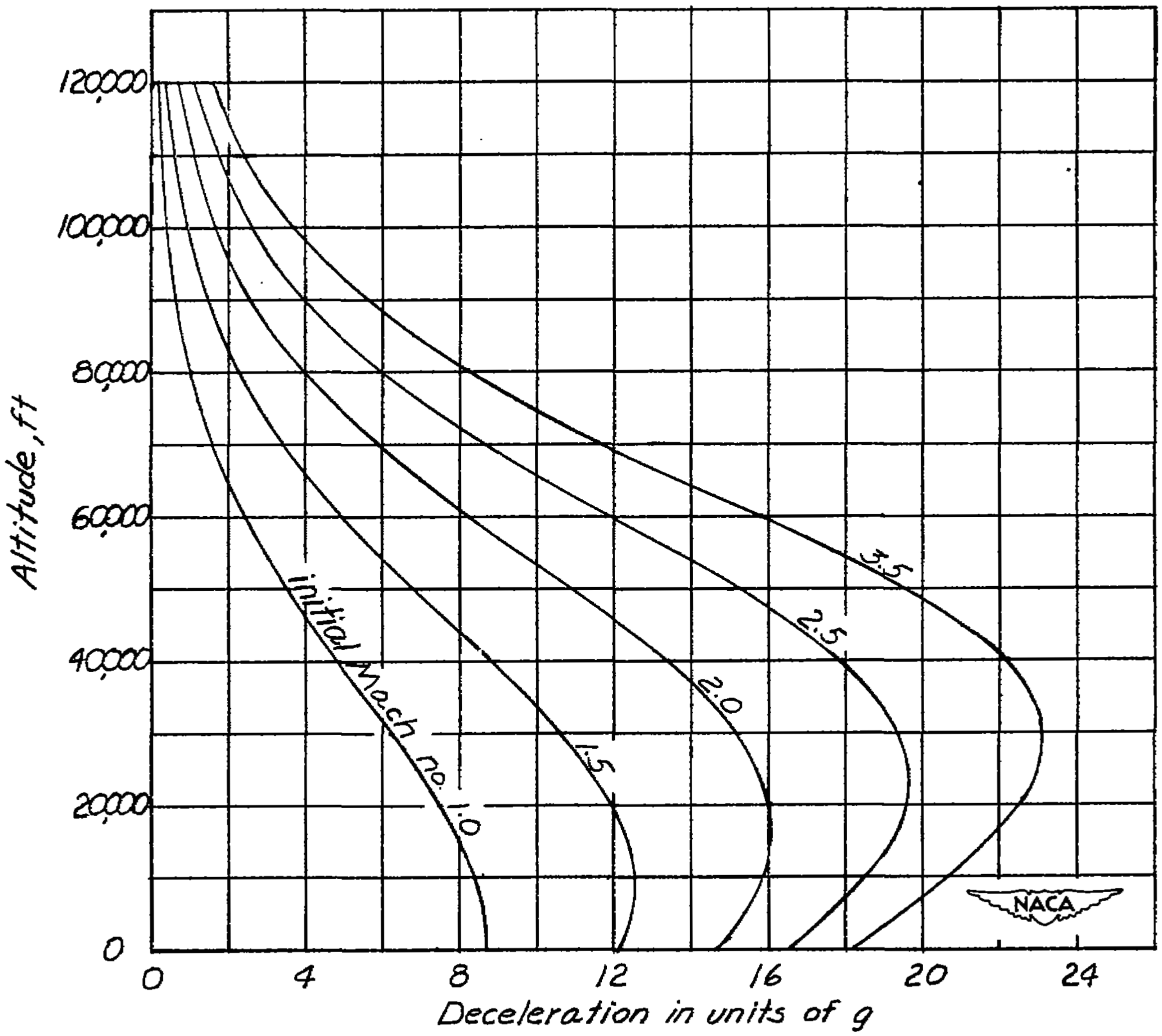


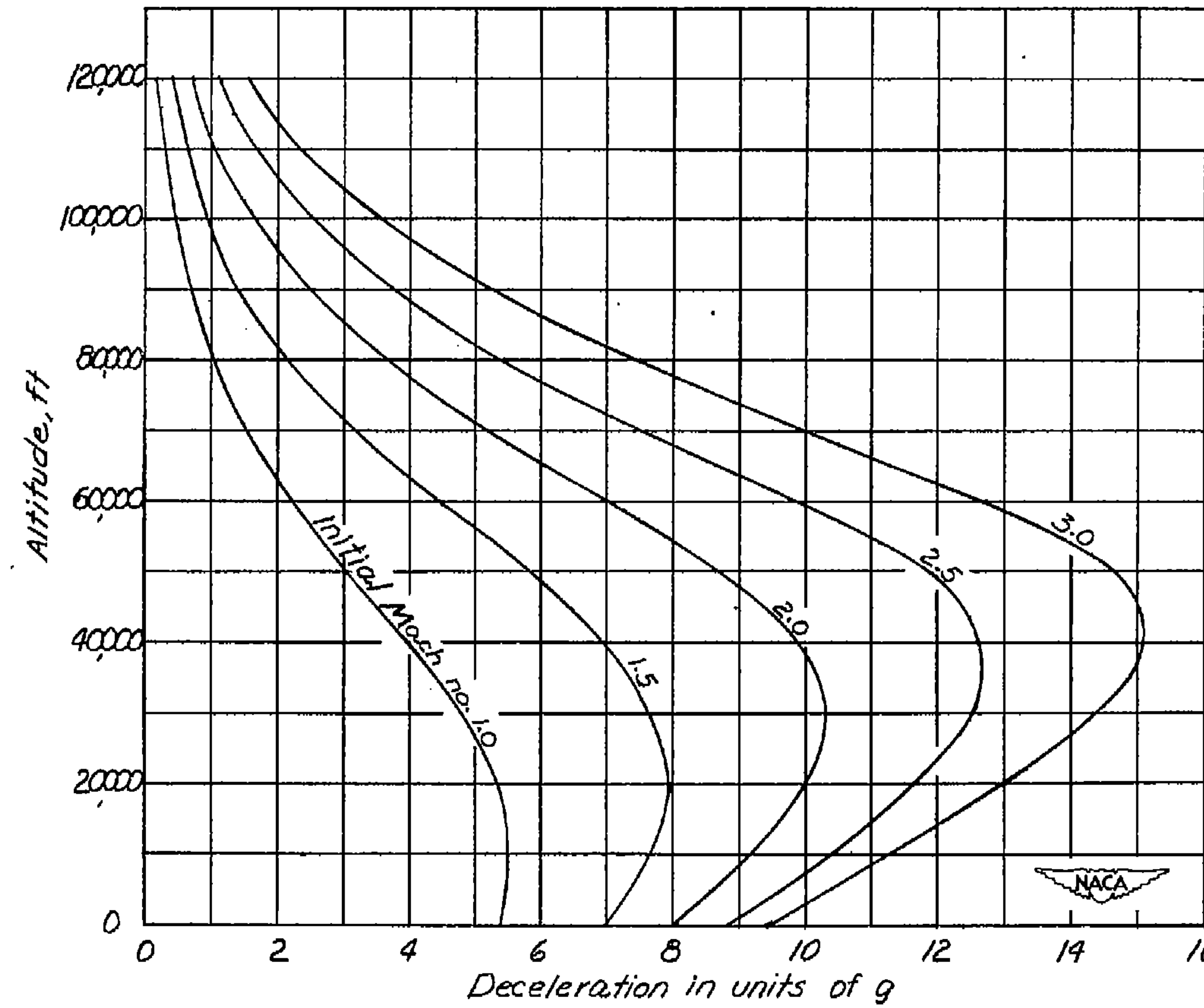
(c) Time = 0.6 second.

Figure 9.- Continued.



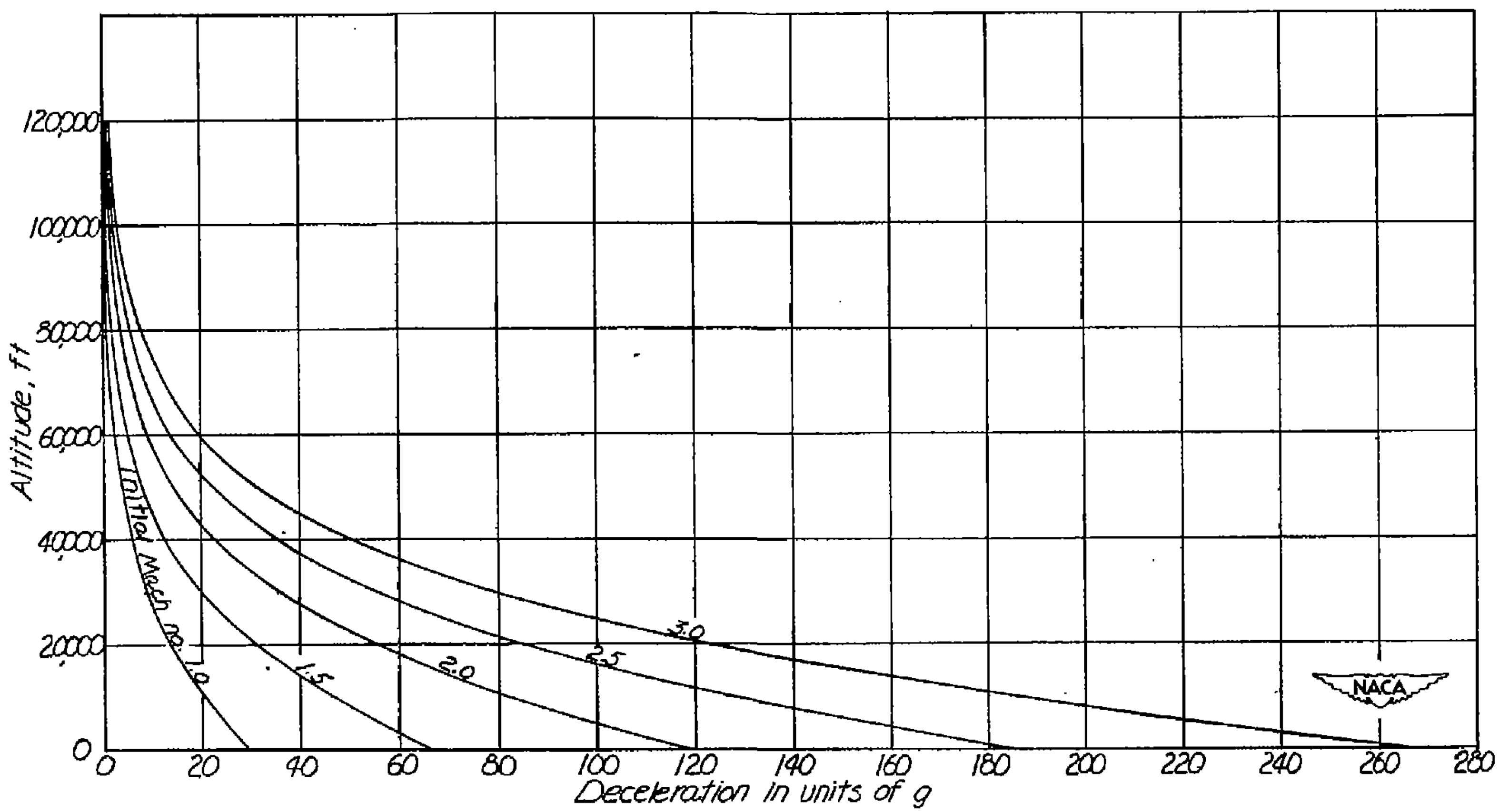
(d) Time = 1.0 second.

Figure 9.- Continued.



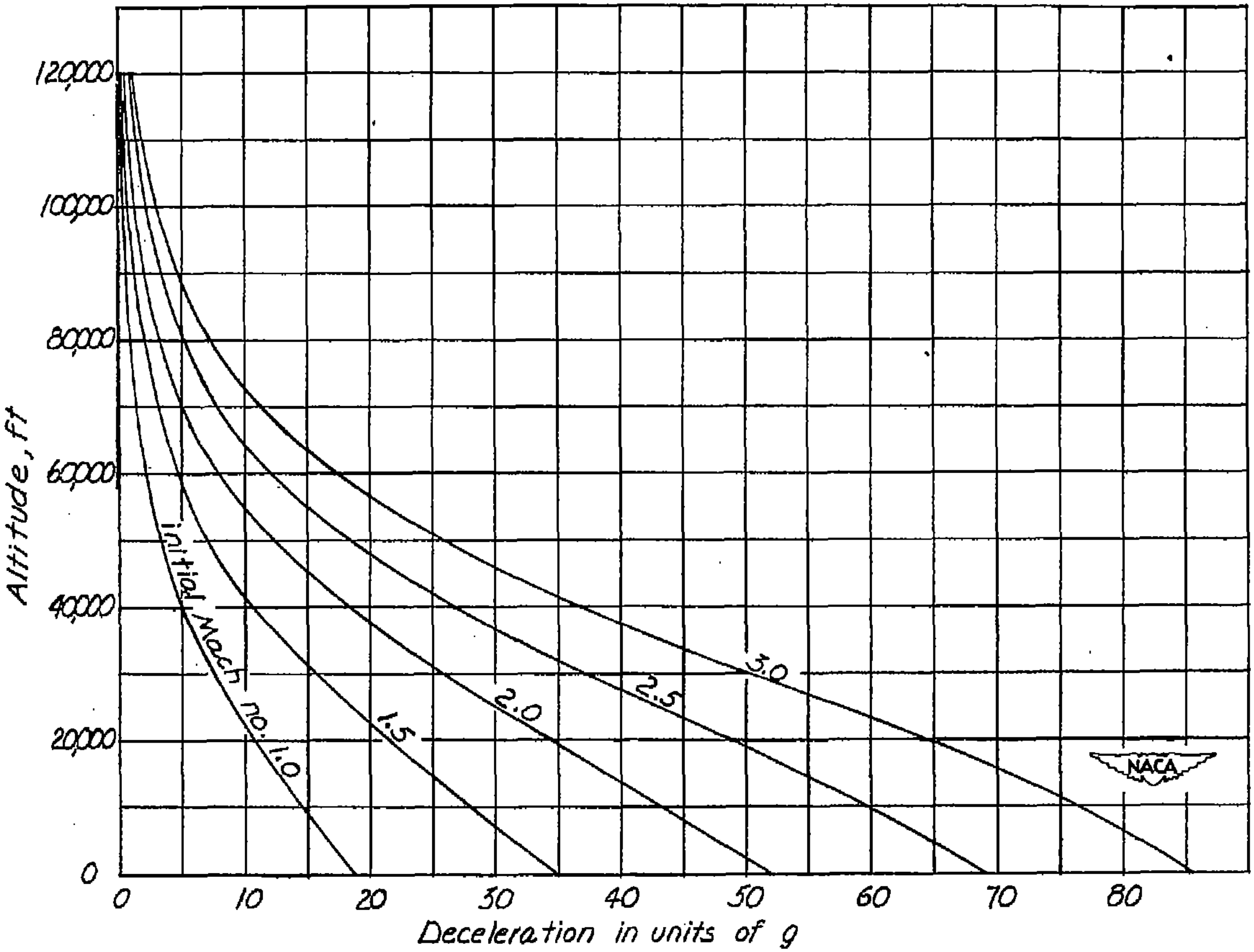
(e) Time = 1.5 seconds.

Figure 9.- Concluded.



(a) Time = 0 second.

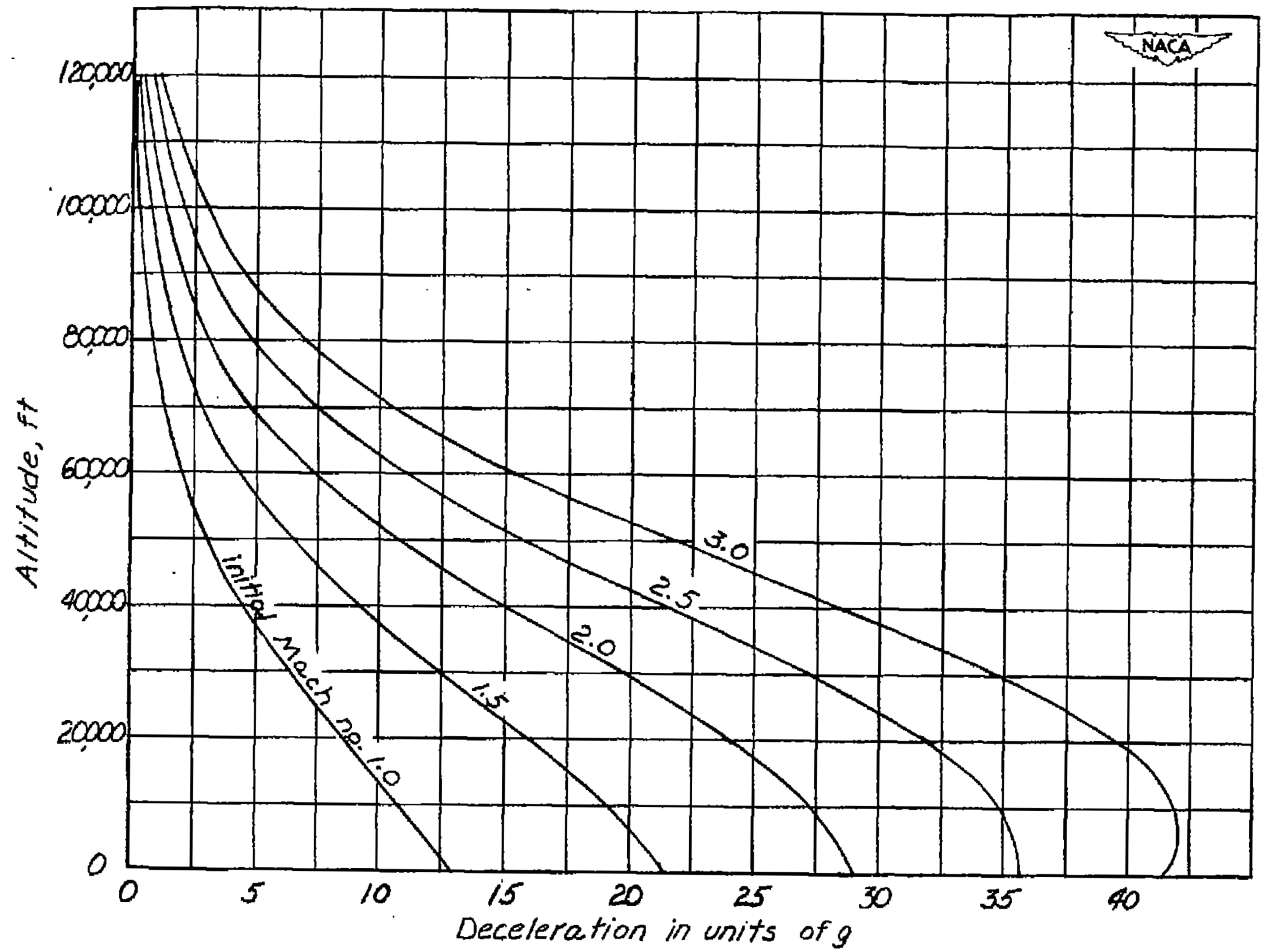
Figure 10.- Calculated decelerations at various time intervals after jettisoning of 1000-pound unstable nose $\left(\frac{W_n}{S_{n_{90}}} = 50 \text{ at } 90^\circ \text{ angle of attack}\right)$ for various altitudes and various initial Mach numbers. Direct-calculation method, assuming constant drag coefficient of 1.0.



(b) Time = 0.3 second.

Figure 10.- Continued.

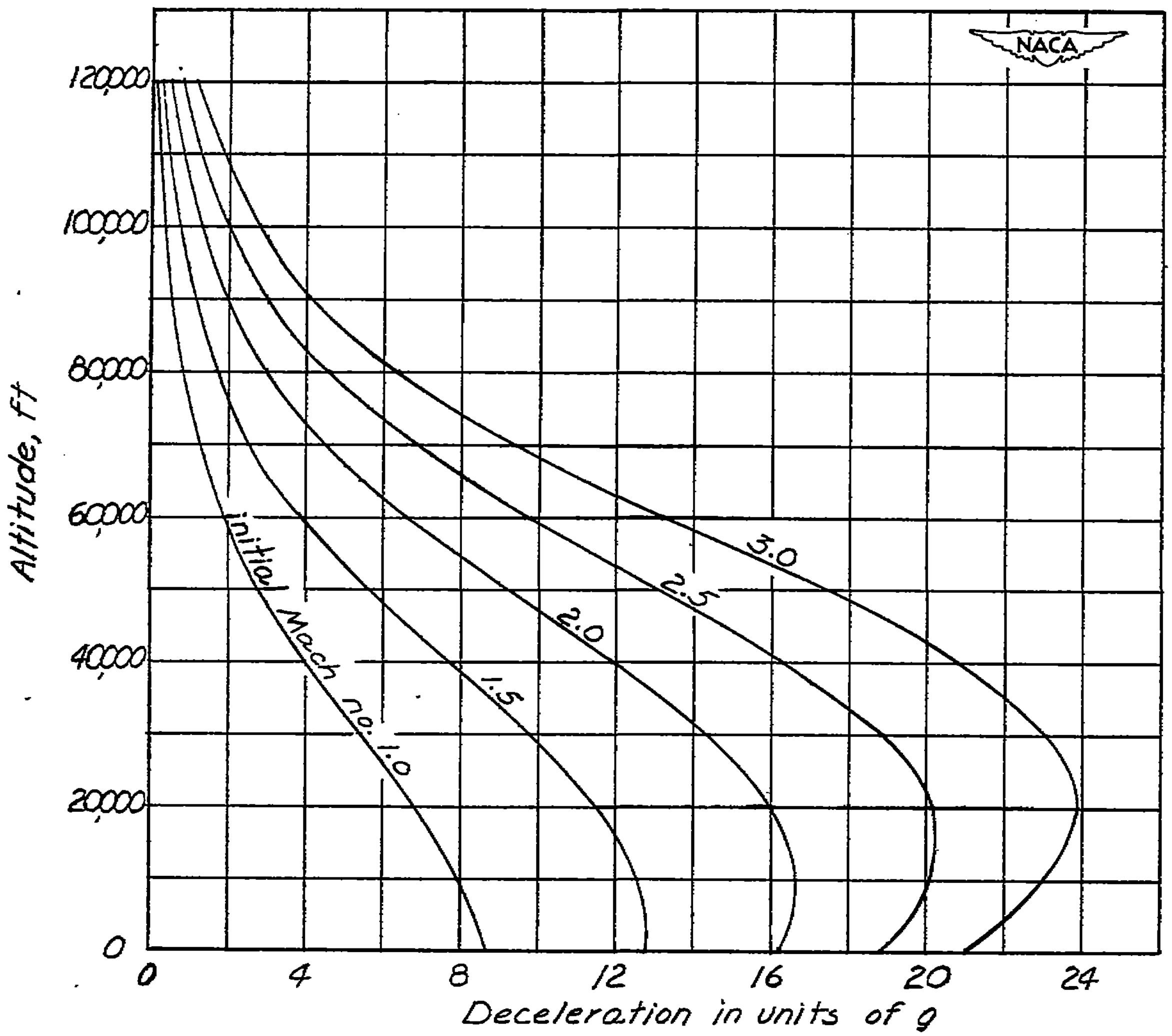
[redacted]



(c) Time = 0.6 second.

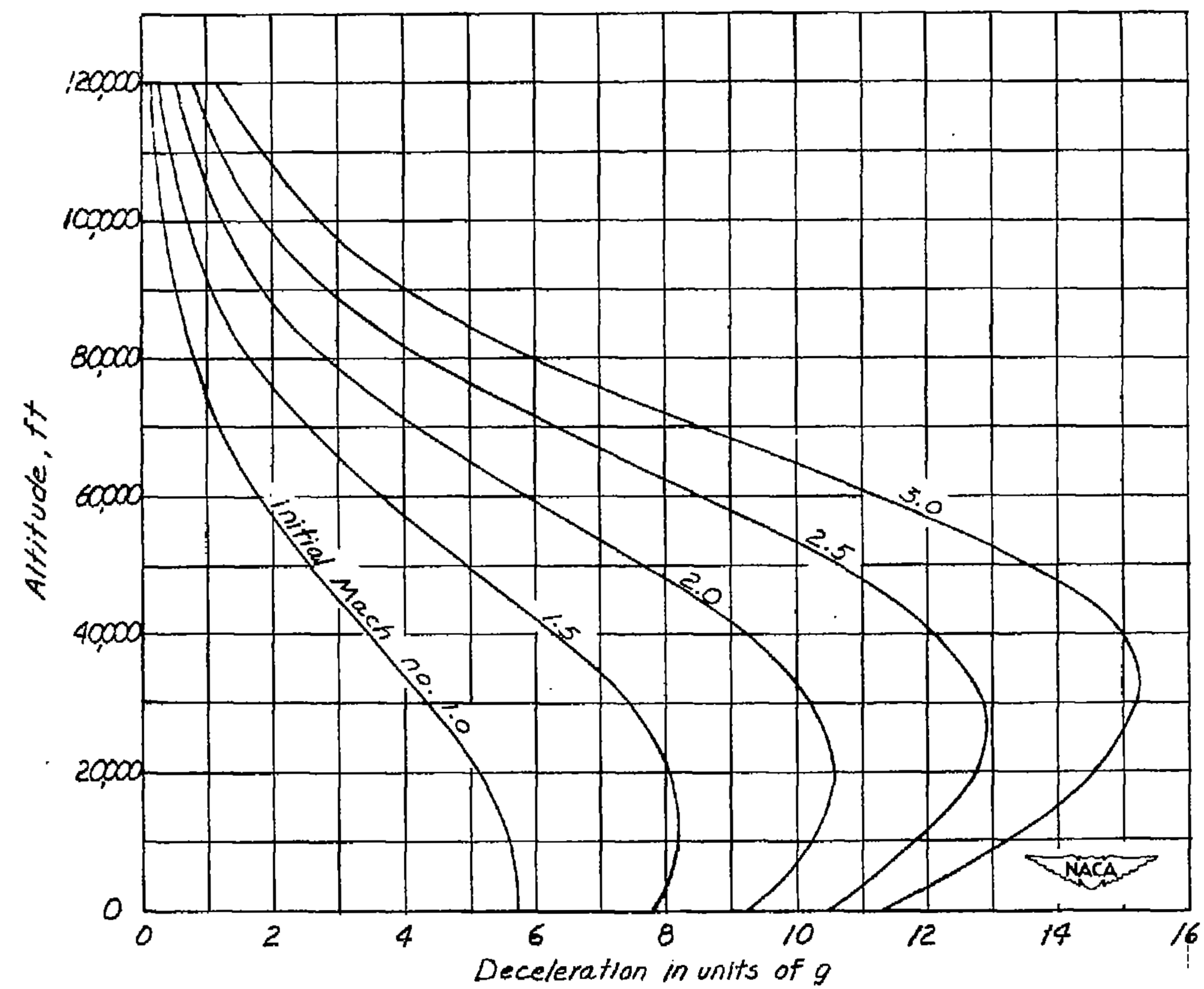
Figure 10.- Continued.

[redacted]



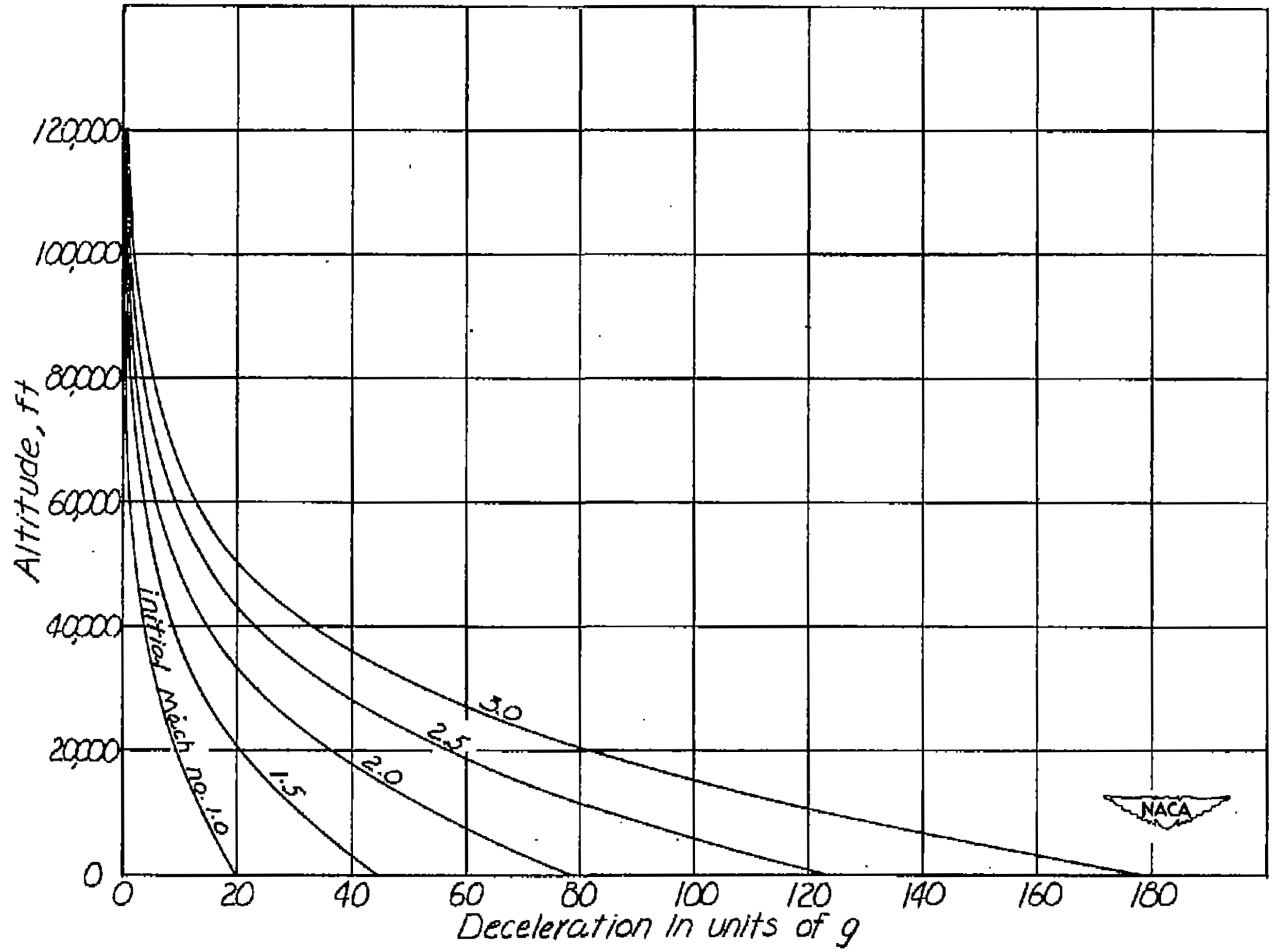
(d) Time = 1.0 second.

Figure 10.- Continued.



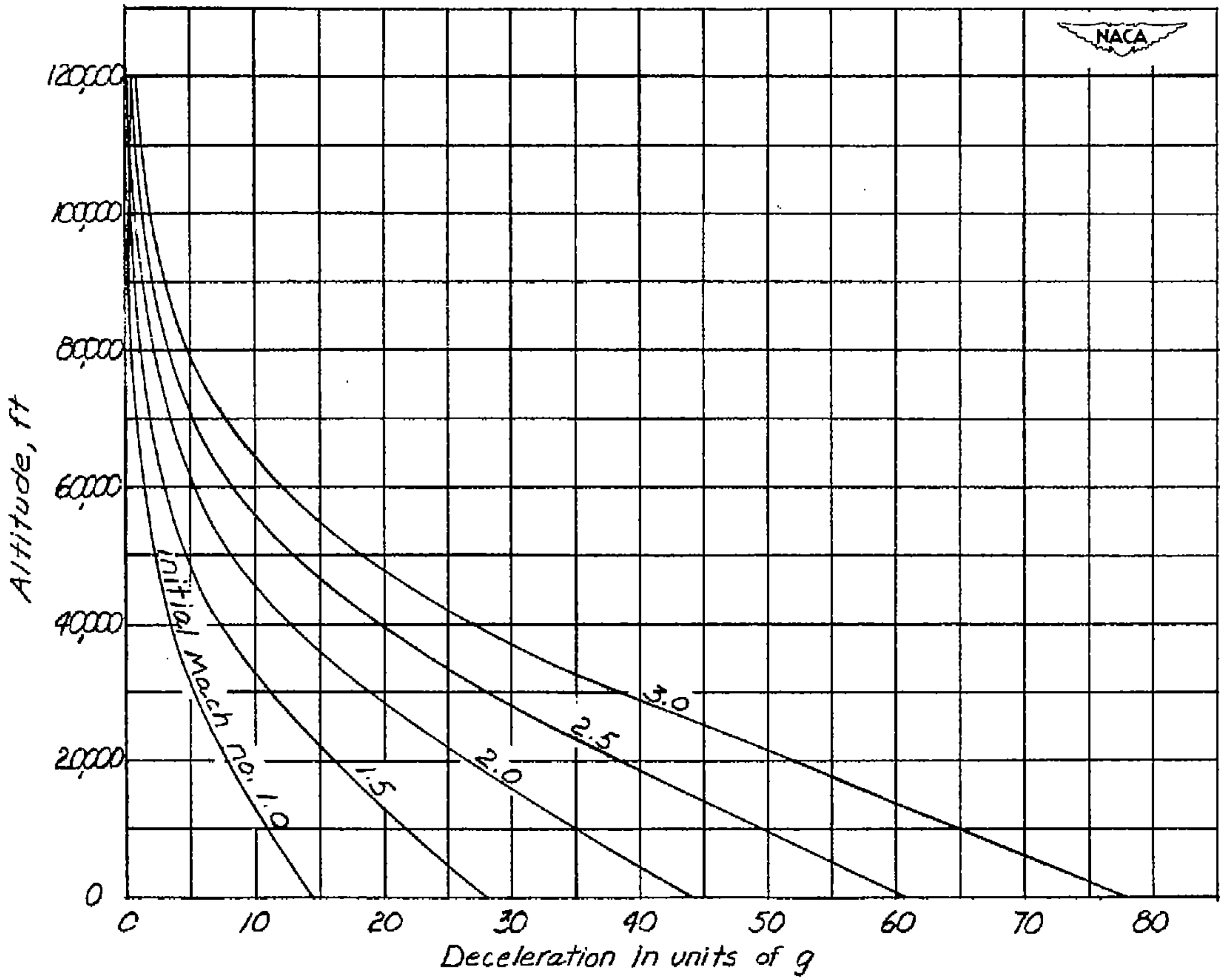
(e) Time = 1.5 seconds.

Figure 10.- Concluded.



(a) Time = 0 second.

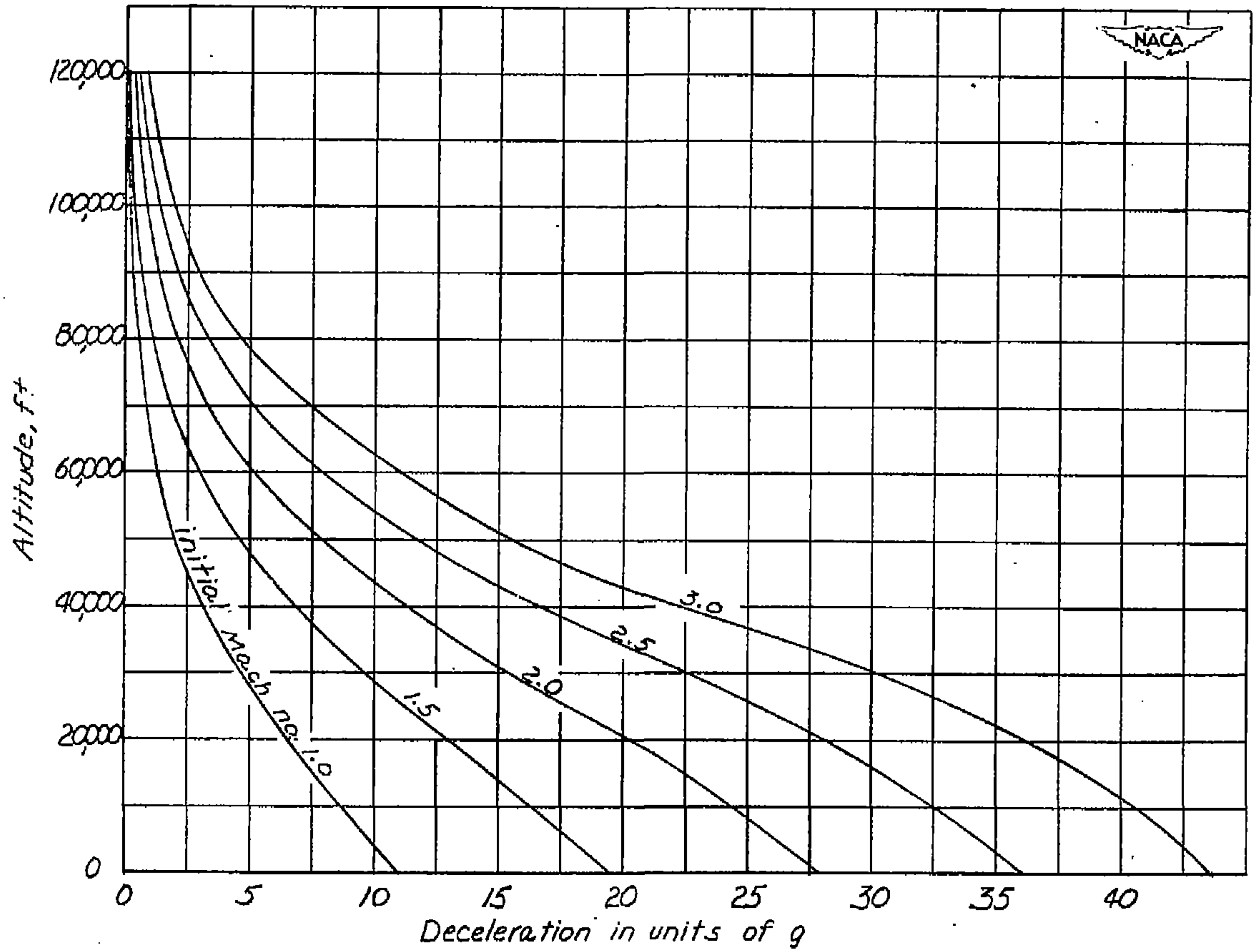
Figure 11.- Calculated decelerations at various time intervals after jettisoning of 1500-pound unstable nose $\left(\frac{W_n}{S_{n_{90}}} = 75 \text{ at } 90^\circ \text{ angle of attack}\right)$ for various altitudes and various initial Mach numbers. Direct-calculation method, assuming constant drag coefficient of 1.0.



(b) Time = 0.3 second.

Figure 11.- Continued.

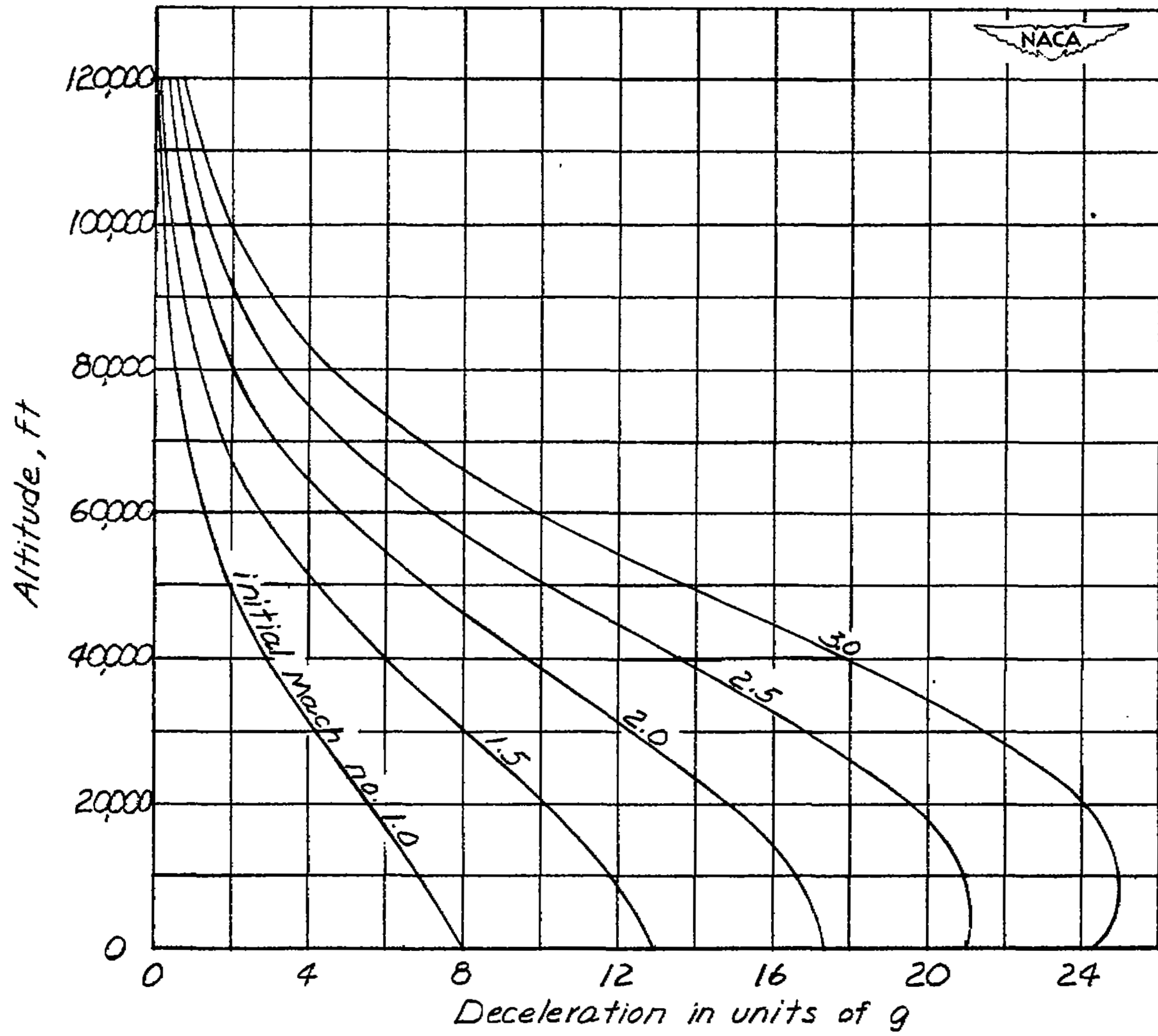
[redacted]



(c) Time = 0.6 second.

Figure 11.- Continued.

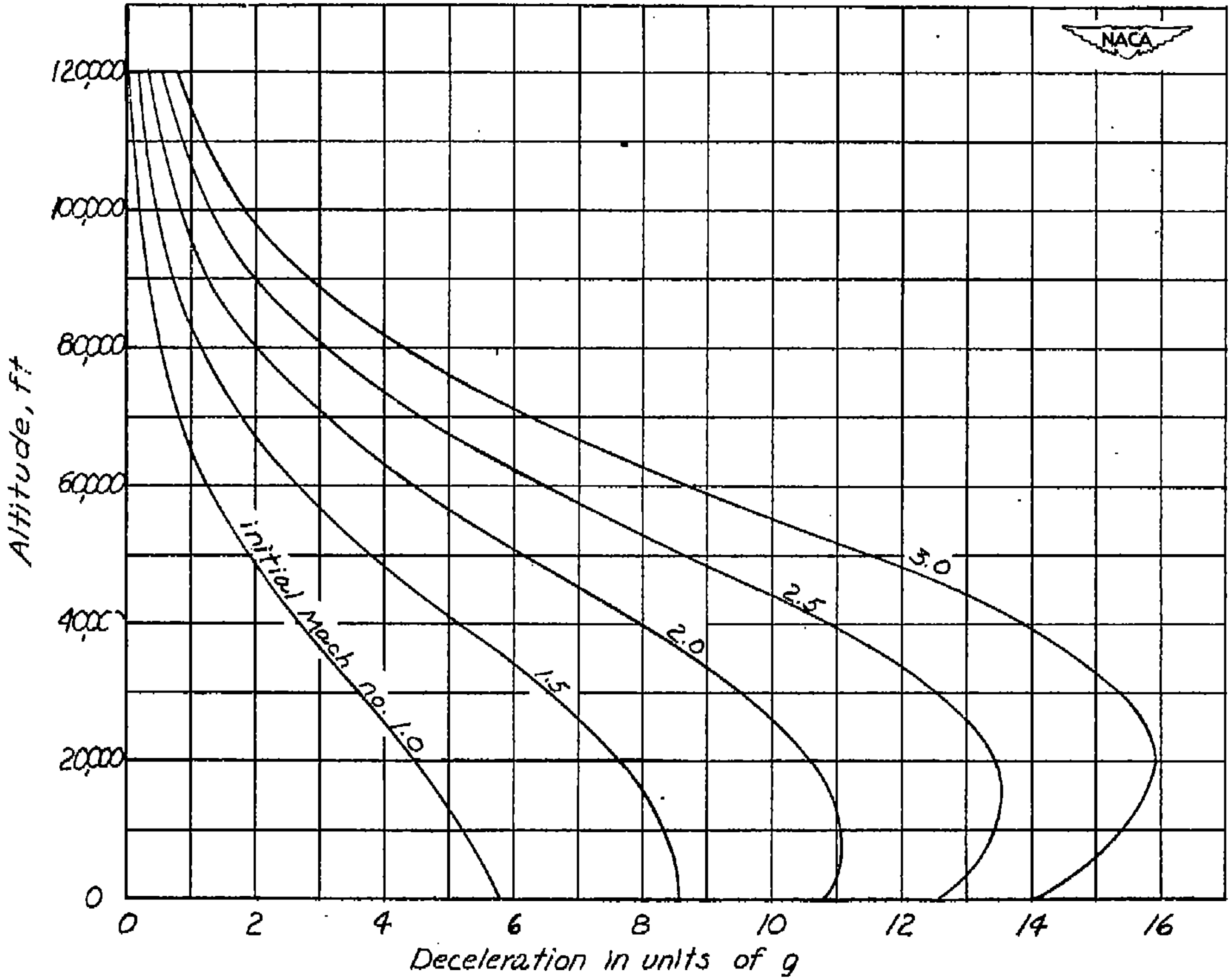
[redacted]



(d) Time = 1.0 second.

Figure 11.- Continued.

[redacted]



(e) Time = 1.5 seconds.

Figure 11.- Concluded.

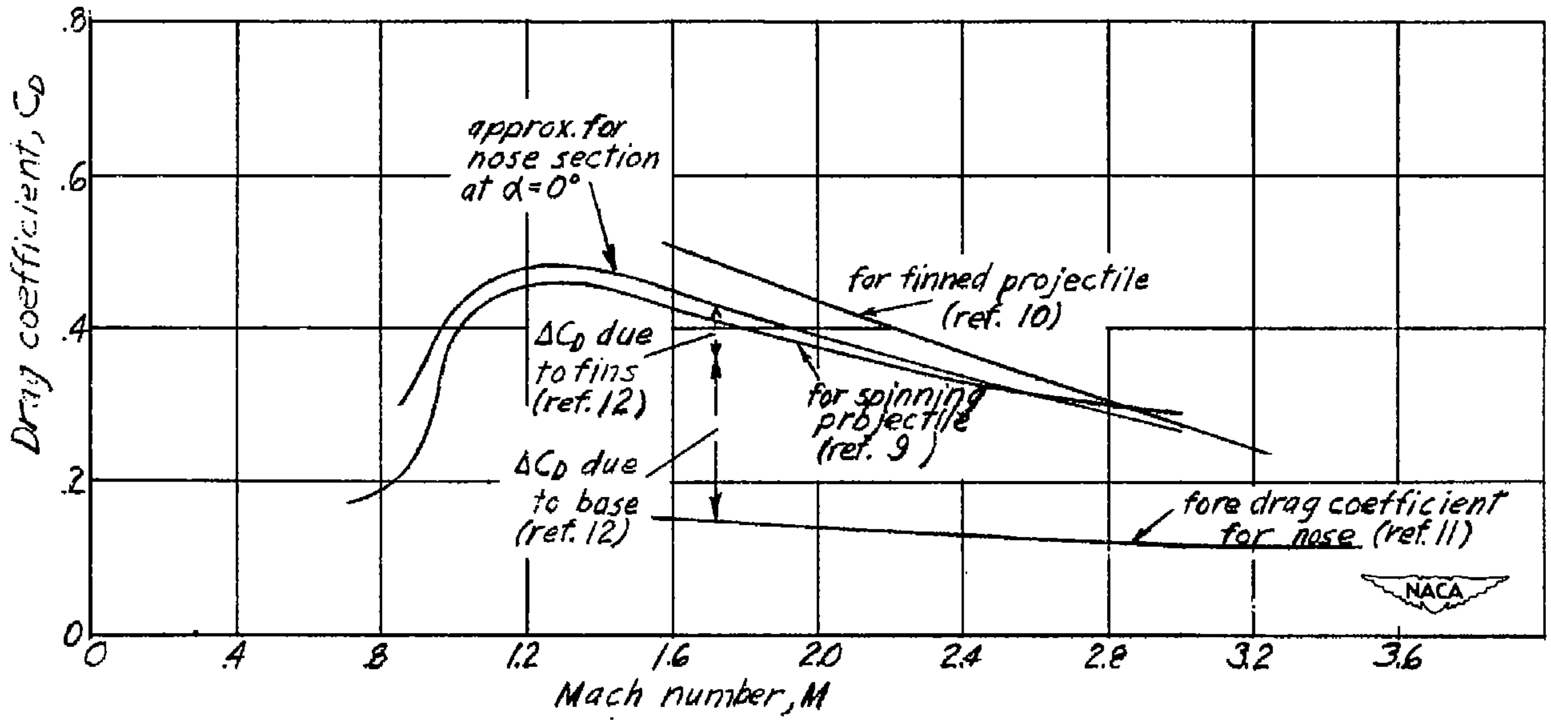


Figure 12.- Variation of drag coefficient with Mach number for projectiles and for the nose at 0° angle of attack.

[redacted]

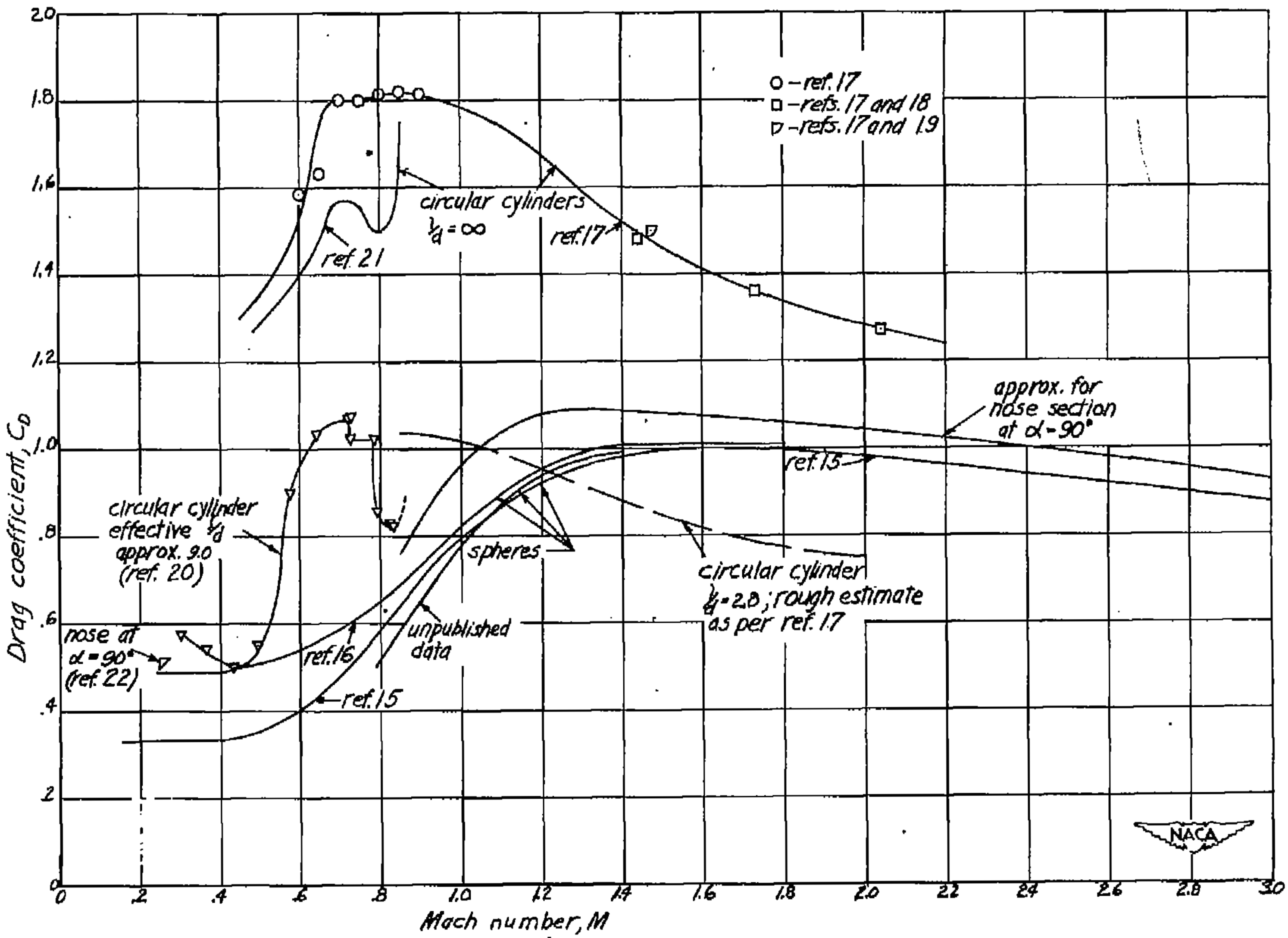


Figure 13.- Variation of drag coefficient with Mach number for spheres, circular cylinders, and the nose section at 90° angle of attack.

[redacted]